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ORIGINAL ARTICLE

# Tariff diversity and competition policy: drivers for broadband adoption in the European Union

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**Abstract** While second-degree price discrimination is standard in commercial practice in many industries, consumer advocates and public interest groups have reacted with skepticism to tendencies to move away from flat rates and introduce greater tariff diversity. This paper uses time-series data to provide an empirical analysis of how the differentiation of broadband tariffs with respect to retail prices affects fixed broadband subscription. The empirical analysis is based on a unique dataset of 10,200 retail broadband offers spanning the 2003–2011 period and including 23 EU member states. Results show that an increase in tariff diversity provides a significant impetus to broadband adoption, wherefore demands by several public interest groups to limit price discrimination in broadband markets should be viewed with some caution as reduced price discrimination may come at the cost of lower penetration rates.

**Keywords** Broadband demand · Tariff diversity · Price discrimination · Dynamic panel data analysis

**JEL Classification** L86 · L96

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## 1 Introduction

Increasing access to and usage of broadband internet has become a national policy priority for most governments since broadband penetration has been identified as a key driver for economic prosperity (e.g., OECD 2008; ITU and UNESCO 2013; Röller and Waverman 2001; Czernich et al. 2011). However, positive economic effects can only materialize if subscribers make use of the deployed infrastructure, which is only partly the case. Notwithstanding substantial efforts, nearly 30% of Europeans had never once used the internet in 2010, and in 2015 still 18% of the EU population aged 16–74 had no usage history (Eurostat 2015). Regarding Next Generation Access (NGA) networks, a recent study reveals that, for instance, in Germany only a small fraction of the deployed fiber infrastructure is actually used.[1]

As a result, in recent years a large body of empirical literature emerged, carving out determinants of broadband adoption (Denni and Gruber 2007; Gruber and Koutroumpis 2013; Kongaut and Bohlin 2014; Briglauer 2014), but despite a general consensus that the price level plays an important role, neither the determinants of broadband internet access prices nor the resulting pricing structure came under increased scrutiny. However, it is utterly important that both are analyzed in order to ensure sound regulation and competition policy in this sector.[2]

Broadband customers in the European Union are accustomed to having to choose from a menu of broadband offerings, varying with respect to down- and upload speeds, contract duration, price structure, and possibly bundled services.[3] Differentiation strategies by Internet service providers (ISPs) on fixed and mobile broadband have broadly been accepted as legitimate business strategies and were generally not a matter of policy concern. However, price discrimination has generated a lively debate in some countries with some public interest groups demanding more uniform tariffs (see, e.g., Odlyzko et al. 2012; Lyons 2013). Critics have claimed that market segmentation leads to consumer confusion and unjustified high prices in the presence of too much variety caused by too many tariffs. Price discrimination in the telecommunications sector, especially usage-based pricing (UBP), is thus seen as a serious threat to consumer welfare. Consequently, different policy actions have aimed at reducing or prohibiting differentiated pricing schemes. For example, the Data Cap Integrity Act of 2012[4] demands that "an Internet service provider may not impose a data cap on the consumers of the provider" (p. 3) and the more recent merger between the fixed broadband providers Charter Communications, Time Warner Cable, and Bright House

[1] FTTH Council Europe (2016), *Der FTTH Markt in Europa: Status, Ausblick und die Position Deutschlands*, only available in German, (see, https://langmatz.de/wp-content/uploads/2016/03/1-jan-schindler-ftthcouncil-der-ftth-markt-in-europa.pdf).

[2] Howell (2008) emphasizes that with price structures, such as flat rates, where low-usage consumers extremely cross-subsidize high-usage customers, customers' true valuations of access and usage are obfuscated. In view of a lack of more precise information operators, regulators, and policymakers might eventually make wrong decisions to invest or to regulate.

[3] Bundles may include any combination of broadband internet, fixed-line telephony, delivered via PSTN or VoIP telephony, TV or entertainment services as well as mobile voice and data services.

[4] Data Cap Integrity Act of 2012, S.3703 – 112th Congress (see, https://www.congress.gov/112/bills/s3703/BILLS-112s3703is.pdf).

Networks in 2016 was subject to the agreement to refrain from differentiated pricing practices by prohibiting usage-based pricing for 7 years.[5] In addition, universal service obligations sometimes explicitly prohibit differentiating prices geographically and/or between consumer types.[6]

On the other hand, academics and regulators have argued in favor of tariff diversity and have stressed its positive effect on broadband adoption and network management. Regarding the supply side, Lyons (2013), for example, considers pricing flexibility a useful tool for operators to spread network costs, to promote greater efficiency, and to recover costs that can be used to invest in future network infrastructure. Regarding the demand side, Bauer and Wildman (2012) show that tariff diversity gives consumers more choices to better fit their bandwidth needs by distinguishing between low-volume and high-volume users. Pointing out that especially inexperienced broadband users find it difficult to predict which online activities they will engage in and how much they will value them, low cost-low usage tier options can be used to incentivize broadband subscription for first-timers.[7] The objective of this paper is to empirically test the relevance of this second effect.

So far, related studies have explored the determinants of (a) broadband demand and (b) broadband prices. The first strand examines socio-economic, geographical, and policy factors, such as income, level of urbanization, and the regulatory regime (e.g., Garcia-Murillo 2005; Lin and Wu 2013; Galperin and Ruzzier 2013; Kongaut and Bohlin 2014). Regarding inter- and intra-platform competition, the former is found to be a stimulus to broadband demand, whereas results for intra-platform competition are ambiguous (Distaso et al. 2006; Bouckaert et al. 2010; Gruber and Koutroumpis 2013; Nardotto et al. 2015).[8] These findings challenge the viability of the existing regulatory framework. It currently targets the effectiveness of wholesale broadband access regulation imposed on the incumbent's first generation network which, however, might impede the rollout of future ultra-fast networks (Briglauer 2014; European Parliamentary Research Service 2015). The second strand analyzes broadband retail prices and shows that data restrictions lead to lower prices and that increased quality, in terms of increased download speed, drives prices upwards (Wallsten and Riso 2010). Calzada and Martínez-Santos (2014) document that DSL-based offers are the most expensive and incumbents' prices exceed those of entrants. The latter may stem from

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[5] See the Memorandum Opinion and Order of the FCC from May 2016, FCC 16.59 (see, http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0510/FCC-16-59A1.pdf).

[6] International Telecommunication Union (see, http://www.itu-coe.ofca.gov.hk/vtm/universal/faq/q1.htm).

[7] Demand for diversified offers is also prevalent in the TV market. In the US, for instance, the cable companies Verizon, Dish, and Cablevision started offering cheaper, slimmed-down bundles of dozens of TV channels as opposed to hundreds, and immediately saw a substantial shift from their installed subscribers and at the same time gained new subscribers (The Washington Post (2015), *Cable companies pare down bloated TV bundles to stem tide of cord-cutters* (see, https://www.washingtonpost.com/business/economy/cable-companies-pare-down-bloated-tv-bundles-to-stem-tide-of-cord-cutters/2015/09/18/ac67a0a8-5e53-11e5-b38e-06883aacba64_story.html).

[8] Broadband competition can occur as facilities-based competition between different technologies (e.g., DSL-, cable-, and fiber-based technologies), referred to as inter-platform competition, or as service-based competition over the same infrastructure through open access provisions at various network layers, referred to as intra-platform competition.

their wider coverage, their reputation or the incumbents' concerns about the price-squeeze tests set by competition authorities.[9]

Yet, with the exception of Haucap et al. (2016), the empirical literature has been silent on the impact of retail pricing structures on demand, though the effect might be ambiguous. Price discrimination in the retail broadband market might either (a) increase demand by allowing suppliers to serve low-value customers without lowering the price for high-value customers, or (b) decrease demand, as consumers may become confused over the variety of tariffs, potentially intended to obfuscate them, and finally reluctant to sign a contract (Spiegler 2006). The success of easy-to-grasp flat rate tariffs, associated with a rather modest price difference between offerings, may suggest that simple tariffs in fact outclass more diverse and complicated offerings when it comes to fostering broadband demand.

In line with the classical industrial economic theory that price discrimination enlarges output and demand, Haucap et al. (2016) provide empirical evidence that an increase in tariff diversity provides a significant impetus to broadband adoption. The authors use an instrumental variable approach to estimate demand for fixed broadband services in 82 countries. To measure tariff diversity on a country-level a dataset comprising over 1000 fixed-line broadband tariffs is used. However, and in comparison to the present study, their analysis is based on a cross-sectional dataset with a relative small number of analyzed fixed broadband plans and a majority of non-OECD countries. Consequently, the authors cannot take into account dynamic developments and their results may not be applicable to more technologically advanced countries like the European Union member states. This paper aims to fill this void.

The present paper analyzes how the differentiation of broadband tariffs influences fixed broadband demand including subscriptions to NGA networks. In the following, the term *tariff diversity* refers to the possibility that each broadband provider may offer potential customers a variety of diverse tariffs to choose from, each associated with a different level of quality. This is often referred to as usage-based pricing when referring to variation in tariffs associated with different bandwidths and data caps. First we account for second-degree price discrimination from selling tariffs with different download speeds, varying contract durations, tiered plans or volume- and time-based pricing, and second, we focus on third-degree price discrimination by selling to different consumer groups, e.g., offering 'student' or special 'internet starter' plans.[10] When price variation is associated with bundling, in which case individual prices are not cleanly identified, we are looking at implicit price discrimination which, however, is not the focus of this paper.[11] The analysis is based on a rich dataset that originally contains 10,200 residential retail broadband offers for 23 European states between

[9] Although retail prices are no longer a matter of continuing regulatory concerns in the EU, they are assessed in order to prevent a "margin squeeze" which occurs when incumbents set wholesale and retail prices with a narrow margin such that a downstream firm cannot survive or effectively compete.

[10] Note that the analysis does not directly test the effect of UBP versus flat rate pricing, as is nicely done in Nevo et al. (2016) for broadband usage. We rather look at price dispersion at an aggregated level, accounting for different forms of second-degree and third-degree price discrimination. Hence, the observed tariff diversity is inevitably influenced by the difference of metered and unlimited offers, but not exclusively.

[11] The impact of bundles is evaluated as a robustness check, see Sect. 3.2.

2003 and 2011. The econometric estimation explicitly accounts for endogeneity due to omitted variables or reverse causality. A multiplicity of measures for price dispersion in conjunction with a broad set of control variables ensures the robustness of the analysis.

The results indicate that broadband demand is positively related to increased tariff diversity, suggesting that policymakers should be lenient toward price discrimination in broadband markets as reduced price discrimination may come at the cost of lower penetration rates. Moreover, facilities-based competition is found to be a stronger driver of broadband penetration than service-based competition. The intention of the European Commission to promote facilities-based competition therefore seems to be the appropriate policy for regulators in order to further promote broadband adoption.

The remainder is structured as follows: Sect. 2 outlines the empirical strategy and provides a detailed description of the dataset. Results are presented in Sects. 3, 4 concludes.

## 2 Model specification and data

### 2.1 Empirical strategy

In line with previous empirical research, broadband adoption is specified as a function of the competitive environment as well as topographic and socio-demographic factors, such as population density and economic prosperity. Plan-specific variables are included and network effects are accounted for by adding the lagged dependent variable. Following Kim et al. (2003) and Cava-Ferreruela and Alabau-Muñoz (2006), the dynamic reduced-form model of fixed broadband adoption for country $i$ at time $t$ reads

$$fbb\_sub_{it} = \alpha + \beta fbb\_sub_{i(t-1)} + \gamma^{'}\mathbf{T}_{it} + \delta^{'}\mathbf{C}_{it} + \varphi^{'}\mathbf{X}_{it} + \theta_i + \lambda_t + \epsilon_{it}, \quad (1)$$

where *fbb_sub* denotes the number of broadband subscriptions. $\beta$ measures endogenous growth in terms of network effects. If the process is stationary, it holds that $|\beta| < 1$. $\mathbf{T}_{it}$, $\mathbf{C}_{it}$, and $\mathbf{X}_{it}$ are vectors of tariff characteristics, market structure as well as demand and costs controls, respectively. Equation (1) also contains country-specific effects, $\theta_i$, and period effects, $\lambda_t$, to control for unobserved heterogeneity across countries and periods, plus an unobservable error term, $\epsilon_{it}$.

#### *2.1.1 Independent variables*

The key tariff characteristics in vector $\mathbf{T}_{it}$ are the monthly access price, the measures for price dispersion, and the advertised download speed. For the price variable a negative effect on broadband adoption is predicted. In accordance with classical industrial economics that price discrimination in final consumer markets may lead to an expansion of output and demand, a positive relationship between tariff diversity and the number of broadband subscribers is expected.[12] The average connection speed is another relevant tariff characteristic that resembles the quality of service. Increased download/upload speeds are predicted to positively affect consumers' willingness to pay, thereby increasing demand for broadband services for a given price level.

In $\mathbf{C}_{it}$ the following market structure related variables are subsumed: (1) the intensity of facilities-based competition, (2) the degree of service-based competition, and (3) the extent of fixed-to-mobile substitution. As suggested by several studies, a positive effect of facilities-based competition on adoption is expected. Given that DSL remains the main form of delivery for broadband services in most European countries, we account for intra-platform competition between different DSL providers. Furthermore, it is common in the telecommunications industry that carriers are active in multiple market segments, causing interdependencies. Whilst incumbent operators may be able to leverage their position in the fixed telephony and narrowband market into the broadband market, the market power of fixed broadband operators is likely constrained by mobile services since mobile telephony subscribers often access the internet via their smartphones. Hence, mobile operators enter into competition with fixed broadband providers. The phenomenon of fixed-to-mobile substitution (FMS), that is, an increasing importance of mobile telephony at the expense of fixed telephony, has been studied intensively (e.g., Ward and Woroch 2010; Barth and Heimeshoff 2014; Grzybowski and Verboven 2016; Lange and Saric 2016) and it has been shown that FMS even affects the broadband market. According to Briglauer (2014), FMS and NGA adoption follow an inverted U-shaped relationship. On the one hand, competition in the legacy market incentivizes investments to escape the competition and gain a firm position in the new frontier market, leading to a positive relationship ("escape competition effect"). On the other hand, too pronounced competition may lower rents and investment capital, eventually yielding a slower average innovation rate and less broadband deployment and adoption in the case at hand ("Schumpeterian effect").

Vector $\mathbf{X}_{it}$ includes supply and demand controls. The costs of deploying and operating networks depend to a large extent on the underlying technology, population density, population dispersion, and geographic conditions. A higher population density and/or a larger share of urban inhabitants allow carriers to exploit economies of scale as they are thus capable of connecting more subscribers to the deployed infrastructure. The rollout per capita is therefore less costly and broadband supply should be promoted. The baseline demand controls are population size, income, and PC penetration. All are predicted to increase broadband adoption via different channels. With the number of broadband connections as the dependent variable, we include the overall number of inhabitants since ceteris paribus a larger population should induce more connected broadband lines. Increases in economic prosperity allow to spend more on information and communication services and PC availability is a prerequisite for fixed broadband usage.

[12] To account for a potential non-linear effect of price discrimination on demand, as too much variety in pricing schemes may eventually make consumers reluctant to buy, a quadratic term was added which, however, turned out to be insignificant irrespective of the underlying measure. Results are not reported but are available upon request.

*2.1.2 Estimation and identification strategy*

The dynamic setup induces potential endogeneity problems that are tackled by using the Arellano–Bond generalized method of moments (GMM) estimator (Arellano and Bond 1991). Other estimation approaches, for example, pooled OLS, fixed-effects or (bias-corrected) least-squares-dummy-variables estimator (LSDVC), are inappropriate in view of the present analysis.[13] We apply the difference GMM instead of the more efficient system GMM estimator since the latter suffers from inconsistency if explanatory variables and individual time-invariant effects are correlated (cf. Arellano and Bover 1995; Blundell and Bond 1998). Individual time-invariant effects capture a broad range of unobserved factors such as consumer preferences, geographic characteristics, and initial infrastructure stock. Each of these variables is correlated with retail prices and subscription levels, rendering the system GMM estimator inconsistent (see, e.g., Grzybowski 2014; Grzybowski and Verboven 2016).

The difference GMM estimator eliminates the country-specific effects, $\theta_i$, and the associated omitted-variable bias by applying a first-difference transformation.[14] Taking first differences, however, induces another source of endogeneity: the lagged dependent variable becomes correlated with the error term. In addition, there are further concerns about endogenous variables. First, observed retail prices are determined by the interaction between supply and demand and are consequently endogenous. Second, due to unobserved demand and supply shocks, the measures of tariff diversity and the market structure variables are likely to be endogenous, too. Third, we face reversed causality between broadband adoption and economic prosperity as increased income may raise telecommunications infrastructure investments, which in turn boost future income (see, Röller and Waverman 2001; Czernich et al. 2011).

Following Arellano and Bond (1991), endogeneity in the first-differenced equation is addressed by applying an instrumental variable approach. The GMM estimator allows us to use both external and internal instruments. Internal instruments are lags of the independent, but potentially endogenous, variables. We employ lagged levels as instruments for (1) the lagged dependent variable, (2) all price-related variables (prices, diversity measures, and income), and (3) the market structure variables. With contract durations up to 24 months and half-yearly data, the fourth lags of the respective variables are implemented. Earlier lags may still be correlated with the error term and would not resolve the endogeneity problem. Besides the inclusion of lagged variables, the instrumentation strategy relies on external instruments in the tradition of Hausman

[13] Results from a pooled OLS estimation are inconsistent because the unobserved time and regional effects are disregarded and the lagged dependent variable is correlated to the error term (Roodman 2007). Employing a fixed-effects model does not resolve the problem either. The demeaning transformation produces inconsistencies due to the large cross-sectional but small time dimension of the dataset (Nickell 1981). Finally, the LSDVC estimator for dynamic unbalanced panel-data models requires strict exogeneity of all regressors (Bruno 2005a, b), which is an unfulfillable assumption in the conducted study.

[14] Estimating Eq. (1) in differences also avoids spurious correlations which occur when non-stationary time series are used in a regression model. For further information see Hamilton (1994). Testing for the presence of a stochastic trend in each variable, we find that the dependent variable is stationary whereas the explanatory variables are integrated of order-zero or order-one. Hence, the specification does not suffer from the spurious correlation problem and cointegration cannot be present. For brevity, results of the Maddala–Wu unit root test are not reported but are available upon request.

(1996) based on neighboring effects. This type of instrument is applied for the retail price and also for the five different measures of price diversity. This instrumentation strategy is reasonable if geographical and thus cost conditions are comparable across neighboring countries but demand shocks are on a national level. For each of the price-related variables the average in the neighboring countries is calculated and then incorporated as an instrument. Using averages levels out potential differences in the geographical and cost conditions across neighboring countries.

### 2.2 Data

Most of the data is drawn from Analysys Mason. Data on the subscription levels are retrieved from Analysys Mason's 'Telecoms Market Matrix' and all tariff-specific information (prices, speed, bundled services, and usage allowance) from the 'Tripleplay pricing study'.[15] The data on broadband tariffs cover, in total, 10,200 residential retail broadband offers by incumbent and entrant operators encompassing both the commercial and technical characteristics over the period 2003–2011 on a semi-annual basis from 23 European countries.[16] Further supply and demand controls are taken from Eurostat, the World Bank, and the Heritage Foundation. Prices and income are measured in euros and are deflated using the consumer price index. All price-related variables, the numbers of subscribers, and the population size are expressed in logarithms in Eq. (1) in order to be interpreted as elasticities. Summary statistics in levels are stated in Table 1 and a detailed description of the dataset, including the variables used for robustness checks, is provided in Table 4.

Fixed broadband adoption is represented as the number of active retail subscribers, constituting the sum of actively used DSL, cable modem, residential fiber, and other fixed broadband connections (including satellite, broadband over power lines, and WiMax).[17] The price variable, *fbb_price*, refers to the average monthly subscription charge for fixed broadband internet service per Mbps download speed.[18] It is calculated as the average access price based on all 10,200 fixed-broadband tariffs included in the dataset per country and period, thus including stand-alone and bundled offers. *fbb_price* reflects the access charge plus any extra access charges from the incumbent for line rental and excluding promotional discounts. For flat rate tariffs these charges equal the final bill whereas they constitute a lower boundary for capped or volume- and time-based tar-

[15] Analysys Mason's 'Tripleplay pricing study' is an international benchmarking survey covering DSL, cable modem, and residential FTTB-based multiplay services for consumers. To ensure data reliability, the information is directly gathered from the companies profiled.

[16] All countries included in this study are listed in Table 3. Not all countries enter the data in 2003, thus, we have an unbalanced panel.

[17] Other metrics commonly used refer to fixed-line broadband penetration levels measured in 100 of population (e.g., used in Cava-Ferreruela and Alabau-Muñoz 2006; Lee et al. 2011; Gulati and Yates 2012; Lin and Wu 2013) or in 100 of households (Höffler 2007; Galperin and Ruzzier 2013). Results do not change qualitatively if the model is estimated with these alternative specifications.

[18] Standardizing the price with the download speed is common in the empirical literature to capture quality differences (Kongaut and Bohlin 2014; Garcia-Murillo 2005; Lin and Wu 2013; Lee et al. 2011).

**Table 1** Summary statistics

| Variable | Measured in | Mean | Std. dev. | Min. | Max. | N |
|---|---|---|---|---|---|---|
| *fbb_sub* | Subscribers | 4,716,463 | 5,896,244 | 32,000 | 26,902,000 | 324 |
| *fbb_price* | Euro | 21.17 | 22.02 | 0.67 | 150.56 | 324 |
| *diversity_sd* | Euro | 17.62 | 15.30 | 0.16 | 98.19 | 324 |
| *diversity_minmax* | Euro | 58.58 | 55.56 | 0.22 | 352.69 | 324 |
| *diversity_minmean* | Euro | 15.45 | 14.34 | 0.11 | 87.39 | 324 |
| *diversity_admedian* | Euro | 11.16 | 9.33 | 0.11 | 49.69 | 324 |
| *diversity_admean* | Euro | 12.85 | 11.01 | 0.11 | 73.64 | 324 |
| *speed* | Mbps | 15.18 | 20.52 | 0.44 | 212.10 | 324 |
| *pc_hh* | 0–1 | 0.68 | 0.14 | 0.29 | 0.97 | 324 |
| *gdp_percapita* | Euro | 6700.80 | 2732.30 | 1459.79 | 12,618.30 | 324 |
| *hhi_inter* | 0–1 | 0.58 | 0.17 | 0.34 | 0.97 | 324 |
| *hhi_intra* | 0–1 | 0.77 | 0.17 | 0.50 | 1.00 | 324 |
| *population* | Inhabitants | 24,063,292 | 25,343,032 | 1,327,439 | 82,534,176 | 324 |
| *urban* | 0–100 | 73.22 | 11.70 | 49.88 | 97.72 | 324 |
| *pop_density* | Inhabitants per $km^2$ | 146.24 | 118.23 | 17.17 | 496.39 | 324 |
| *fms* | 0–1 | 0.22 | 0.07 | 0.08 | 0.42 | 324 |
| *fms_sq* | 0–1 | 0.05 | 0.04 | 0.01 | 0.18 | 324 |
| *bundles_share* | 0–1 | 0.40 | 0.34 | 0 | 1 | 324 |
| *caps_share* | 0–1 | 0.54 | 0.47 | 0 | 1 | 324 |
| *cost_cons* | Percentage (2010 = 100) | 105.37 | 29.56 | 67.41 | 254.66 | 314 |
| *investment_freedom* | 0–100 | 76.42 | 11.20 | 50 | 95 | 324 |
| *business_freedom* | 0–100 | 80.77 | 10.55 | 53.7 | 100 | 324 |
| *telecom_rev* | Euro | 1,400,657,284 | 1,596,697,482 | 55,694,072 | 5,617,589,760 | 311 |
| *inter_high* | 0/1 | 0.66 | 0.47 | 0 | 1 | 324 |
| *mobile* | Subscribers | 901,478 | 1,237,031 | 7535 | 6,175,000 | 256 |
| *av_fbb_price* | Euro | 19.51 | 16.81 | 1.26 | 122.30 | 324 |
| *av_diversity_sd* | Euro | 17.34 | 10.44 | 0.97 | 49.35 | 324 |
| *av_diversity_minmean* | Euro | 15.02 | 11.49 | 0.65 | 77.39 | 324 |
| *av_diversity_minmax* | Euro | 57.95 | 39.03 | 2.69 | 200.05 | 324 |
| *av_diversity_admedian* | Euro | 10.93 | 6.99 | 0.52 | 35.85 | 324 |
| *av_diversity_admean* | Euro | 12.56 | 7.92 | 0.70 | 36.40 | 324 |

iffs. Since there is no information available on the number of subscribers to each plan, the price is calculated as an unweighted average per country and period.

The measures for a country's tariff diversity are based on the original dataset likewise, but only including broadband-only offers, due to the impossibility of disentangling the price components.[19] Precisely, tariff diversity is calculated as the following five measures of central tendency per country and period: the standard deviation (*sd*), the difference between minimum and mean (*minmean*), the difference between minimum and maximum (*minmax*), the average absolute deviation from the median (*admed*), and the average absolute deviation from the mean (*admean*). As consumption decisions might be somewhat sluggish due to habits and contractual obligations, the price and diversity measures are lagged by one period.

The variable *speed* is calculated as the unweighted average download speed in country $i$ at time $t$ using all 10,200 offered tariffs. It refers to the average advertised maximum download speed in Mbps and not to speeds guaranteed to users associated with a monthly subscription. The realized speed might vary due to congestion or the distance between the households and its ISP's cabinet.

The intensity of competitive rivalry between different technologies is expressed as the Herfindahl-Hirschman Index (HHI) of DSL, cable, fiber as well as all other fixed broadband technologies and is denoted by *hhi_inter*. Service-based competition, *hhi_intra*, is calculated as the HHI between the incumbent and the entrants' share in the national DSL market. The HHI is defined as the sum of technologies' (operators') squared market shares. A higher HHI is equivalent to a more asymmetric market structure, implying less competition between the technologies (operators). The intensity of fixed-to-mobile substitution (*fms*) is expressed as the share of fixed landlines in the total number of fixed landlines and mobile telephony subscriptions.

The included cost conditions are *pop_density*, measured as the number of inhabitants per $km^2$ of land area, and *urban*, the share of urban population. Since these supply controls vary within countries, some information on the local heterogeneity of access markets is lost by using national averages. However, it is reasonable to assume that the effects of these drivers are visible at an aggregated level. Income is measured as the quarterly GDP per capita (*gdp_percapita*) and *pc_hh* expresses the percentage of households with access to a PC over one of its members.[20] Network effects are considered by adding the lagged dependent variable which denotes the aggregate demand in the previous period and measures the installed subscriber base.

[19] To illustrate some features of broadband tariffs that influence the price variable and the measures for tariff diversity, we take a closer look at the broadband plans offered by one Hungarian ISP in the fourth quarter of 2011. In total, the ISP markets 51 tariffs with monthly access prices ranging from 7.3 to 49.3 euro with an average of 27.8 euro. This price diversity can be attributed to second- and third-degree price discrimination. Regarding the former, the download speed ranges from 1 to 15 Mbps, resulting in significant differences in the average monthly access price (7.3 vs. 31.1 euro for stand-alone offers). In addition, contract durations vary between 12 and 24 months causing, on average, a price difference of 6 euro for contracts with a download speed of 1 Mbps. The ISP also offers seven volume-based plans that are considerably cheaper than flat rates with the same download speed of 1 Mbps (17.2 vs. 27.2 euro). Regarding third-degree price discrimination, there are two stand-alone offers with 5 Mbps download speed available to students only. In comparison to the regular plan a student saves 2 euro, or put differently, a non-student pays a price premium of 11%.

[20] Note that the information presented only covers desktop PCs and that this particular market has been relatively stagnant in recent years as an increasing share of people have chosen to buy more portable formats, such as laptops, netbooks or tablets.

## 3 Empirical results

Estimation results from the baseline specification, incorporating the different measures of tariff diversity, are presented in Table 2. Columns (1)–(5) state the results, measuring tariff diversity by the standard deviation of retail prices (*sd*), the difference between minimum and mean (*minmean*), the difference between minimum and maximum (*minmax*), the average absolute deviation from the median (*admed*), and the average absolute deviation from the mean (*admean*), respectively.

Due to the first-difference transformation of the GMM estimator, the residuals have a moving average structure and are possibly first-order autocorrelated. The null of no autocorrelation is rejected for AR(1) and AR(2) but not for a higher order, confirming that deeper lags have to be used as instruments. Serial correlation at order one in the first-differenced errors is a consequence of the transformation and does not imply that the model is misspecified. Autocorrelation of a higher-order AR($s$), however, indicates that the moment conditions are not valid and that the $s$-th lag of the dependent variable is not a valid instrument. To test for the exogeneity of the included instruments, the Sargan–Hansen's $J$ test is applied. With $p$ values between 0.15 and 0.40, the test statistics indicate that the null hypothesis of valid over-identifying restrictions cannot be rejected in either regression. The reported standard errors are robust to arbitrary forms of heteroscedasticity and autocorrelation.

### 3.1 Main results

Irrespective of the included measure of tariff diversity, all significant variables have the expected signs. The lagged subscription level, $fbb\_sub_{t-1}$, is highly significant and substantial (0.64–0.66), pointing to the importance of network effects which autonomously push adoption in the broadband market. The retail price elasticity is negative and with coefficients between $-0.04$ and $-0.06$, the long-run elasticities are estimated to lie in the interval $[-0.168, -0.112]$.[21] In the long run a price decrease of 10% induces an increase of 52,824–79,237 connections on average which, for instance, nearly resembles half of the fiber-based connections in Germany at the end of 2011.

The coefficients of the diversity measures are positive and significant in each specification, verifying the findings in Haucap et al. (2016). Although the coefficients are only weakly significant at the 10%-level (and for some robustness checks at the 5%-level), the persistent positive signs suggest that there is in fact a positive effect.[22] Regarding the economic significance the effect is less pronounced than for prices, but still noticeable. A 10% increase in tariff diversity, results on average in nearly 50,000

[21] One advantage of the dynamic estimation approach is the possibility to disentangle short and long-run elasticities. While the short-run elasticities are directly estimated as the coefficients $\gamma_i$, $\delta_i$, and $\varphi_i$, the long-run elasticities can be easily obtained as the fraction of the coefficient and the "speed of diffusion", $1 - \beta$.

[22] Considering the number of DSL, cable, and fiber subscribers separately as the dependent variable, yields comparable results: A positive statistically significant effect of price discrimination on the number of DSL and cable subscribers, and a positive, however, statistically insignificant effect on fiber. The latter at least suggests that price discrimination does not slow down NGA adoption.

**Table 2** Main results

| Dependent variable: *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*fbb_sub* | 0.642*** | 0.645*** | 0.642*** | 0.642*** | 0.662*** |
| | (0.059) | (0.062) | (0.067) | (0.059) | (0.059) |
| L.*fbb_price* | − 0.054** | − 0.060** | − 0.040** | − 0.054* | − 0.048* |
| | (0.028) | (0.029) | (0.019) | (0.030) | (0.027) |
| L.*diversity_sd* | 0.039* | | | | |
| | (0.022) | | | | |
| L.*diversity_minmean* | | 0.044* | | | |
| | | (0.024) | | | |
| L.*diversity_minmax* | | | 0.028* | | |
| | | | (0.016) | | |
| L.*diversity_admedian* | | | | 0.039* | |
| | | | | (0.023) | |
| L.*diversity_admean* | | | | | 0.034* |
| | | | | | (0.021) |
| *speed* | 0.000 | − 0.000 | 0.000 | 0.000 | − 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| *hhi_inter* | − 0.949** | − 0.996** | − 1.021*** | − 0.931** | − 0.924** |
| | (0.410) | (0.417) | (0.365) | (0.407) | (0.401) |
| *hhi_intra* | − 0.129 | − 0.0961 | − 0.150 | − 0.0897 | − 0.106 |
| | (0.151) | (0.143) | (0.155) | (0.145) | (0.139) |
| *fms* | 4.331** | 3.795*** | 4.073*** | 4.548*** | 4.275*** |
| | (1.736) | (1.398) | (1.538) | (1.734) | (1.620) |
| *fms_sq* | − 8.435*** | − 7.875*** | − 8.447*** | − 8.880*** | − 8.333*** |
| | (3.260) | (2.739) | (3.008) | (3.313) | (3.084) |
| *pop_density* | − 0.002 | 0.003 | 0.003 | 0.001 | 0.001 |
| | (0.012) | (0.012) | (0.013) | (0.013) | (0.012) |
| *urban* | 0.026 | 0.009 | 0.001 | 0.020 | 0.025 |
| | (0.028) | (0.036) | (0.031) | (0.032) | (0.027) |
| *gdp_percapita* | 0.295*** | 0.240*** | 0.279*** | 0.312*** | 0.305*** |
| | (0.076) | (0.061) | (0.069) | (0.078) | (0.077) |
| *pc_hh* | 1.095*** | 1.158*** | 1.064*** | 1.029*** | 0.965*** |
| | (0.368) | (0.368) | (0.332) | (0.361) | (0.334) |
| *population* | 1.314 | 0.557 | 0.799 | 1.228 | 1.062 |
| | (1.063) | (0.971) | (0.920) | (1.060) | (1.050) |
| *N* | 301 | 301 | 301 | 301 | 301 |
| Sargan test $\chi^2$-stat | 80.65 | 76.68 | 75.48 | 84.24 | 85.39 |

**Table 2** continued

| Dependent variable: *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| $p$ value | 0.25 | 0.36 | 0.40 | 0.17 | 0.15 |
| AR(4), Prob $> z$ | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

new connections in the long run. Supporting the classical perspective, price differentiation and diversified tariff structures seem to increase broadband adoption, most likely by attracting consumers with a low willingness to pay. This effect thus seems to prevail over a potential negative effect from segmenting consumers to extract more surplus. Consequently, the results suggest that prohibiting price discrimination can impede broadband adoption as some consumers may not find a suitable offer. Claims that merely flat rate tariffs, associated with a modest level of price dispersion, should be offered should therefore be viewed with some caution.[23]

Regarding the market structure variables, we observe a clearly negative impact of concentration in the fixed broadband market, or put differently, a positive impact of facilities-based competition. The same does not hold for service-based competition. Following Nardotto et al. (2015), a possible explanation might be that local loop unbundling entry only triggered broadband subscriptions in the early stage of adoption, but no longer when the market matured. The current emphasis on regulated wholesale access with the objective of encouraging investments by both incumbents and entrants might not be as effective as promoting inter-platform competition. In line with this finding, the European Commission aims at re-designing the regulatory framework in order to encourage investments in new but capital-intensive ultra-fast broadband networks, since the current telecommunications policies and regulation seem to oppose these attempts (European Parliamentary Research Service 2015). As in Briglauer (2014), a non-linear relationship with respect to *fms* is detected. The optimal competitive market condition for broadband adoption is estimated to range between 24.1 and 25.7%. A European average of $\overline{fms} = 22.1\%$ suggests that the escape competition effect is dominated by the Schumpeterian effect; fierce competition in the voice market might have slowed down the deployment of (ultra-fast) broadband and its adoption.[24]

[23] From a dynamic perspective, as argued by Heatley and Howell (2010), price discrimination can also enable firms to increase welfare by accessing scale economies (static efficiency gains) and to introduce a new technology earlier than under the counterfactual of a single price by capitalizing on economies of scale arising from a steeply-decreasing average cost curve (dynamic efficiency gains). The latter aspect might be especially important for fiber-based technologies given that its demand is still modest in many countries.

[24] Note that $\overline{fms}$ is a simple average that gives equal weights to every country and period, independently of the population size, and potentially obfuscating considerable variation between countries and over time. In the beginning of the sample period a large share of fixed-line telephony was common. However, during the sample period and especially in recent years more and more subscribers have cut the cord. Given the significant decline in the number of fixed-line telephony subscribers, some countries went from “not

The demand controls are positive and highly significant, providing evidence that adoption increases in income and pointing to the necessity of complementary products and skills and overall ICT affinity (cf. Bauer et al. 2014). In contrast, neither *speed* nor one of the cost controls is statistically different from zero, which is likely due to the low degree of variation and the aggregation at the national level.

### 3.2 Robustness checks

This section presents additional estimations which confirm the findings from the previous section (see Tables 5, 6, 7, 8, 9 in the "Appendix").[25] Regarding the main variable of interest, we find a positive effect of the degree of price discrimination throughout all specifications. Thus, irrespective of the measure of tariff diversity and the included control variables, price discrimination in the broadband market is found to foster adoption.

We start by investigating whether the results are driven by low income countries, as one could infer from Haucap et al. (2016). In order to test whether the positive effect of tariff diversity persists for higher incomes and probably more data-intensive broadband demand, the sample is split in half by restricting the analysis to observations with a quarterly income per capita above 7000 euro. As can be seen in Table 5, the results do not change qualitatively.

Second, additional dimensions of fixed broadband plans are scrutinized. Table 6 presents the estimation results including the share of bundled[26] and tiered tariffs. Both may be used as second-degree price discrimination mechanisms, allowing (a) to offer packages of services which satisfy different needs, and (b) to vertically differentiate offers in the quality domain, now commonly referred to as "versioning". The coefficients of both variables are positive and mostly significant, affirming that data caps and other forms of differentiation seem not to impede broadband adoption but rather to stimulate it. While bundles may reduce the perceived cost of the service, capped plans are usually cheaper than unlimited offers for the same quality (see, e.g., Wallsten and Riso 2010) and allow low cost-low usage offers for low-value customers who may otherwise refrain from buying. This is particularly interesting since it is service quality-based discrimination that has been the subject of the controversy in the public and policy debate. By controlling for the share of tiered plans separately, some part of

Footnote 24 continued
enough" to "too much" competition in comparison to the estimated optimal competitive market condition for broadband adoption. Other countries approached the optimum in the last years of the sample period. The finding that the Schumpeterian effect dominates the escape competition holds for all included Central and Eastern European countries in all periods. Moreover, for example, in the Netherlands and in Finland market conditions significantly shifted toward mobile services, wherefore the Schumpeterian effect dominates since 2005/2006. In other countries such as Spain, France, and Sweden the measure for *fms* fell as well, but remained close to the optimal level. Only in the UK did the escape competition prevail in all years, however, closely approaching the estimated optimum.

[25] Variable descriptions can be found in Table 4.

[26] Stand-alone offers are by far the most common (46.2%), followed by double-play (28.9%) and triple-play offers (18.3%) of fixed broadband and fixed voice telephony and/or TV. Only a comparatively small share of offers include mobile services.

the positive effect of tariff diversity is extracted. The remaining positive coefficients of the different diversity measures assure that generally second- and third-degree differentiation, e.g., due to different contract durations and speeds or tariffs targeting different consumer groups, are not an impediment to broadband demand. All other previous results are confirmed.

Third, further cost and demand controls are added (Table 7). Construction costs, mostly due to digging, are substantial for network providers and influence operators' rollout and price setting. Following the line of argument in Briglauer (2014), the per capita costs of deployment and maintaining might be reduced with an increased number of connections in densely populated regions, but at the same time carrying out these works might be pricier in urban areas. Accounting for these counteracting forces, an interaction term *urban*cost_cons* is included, where varying costs of construction are captured by the construction price index. However, no significant effect is detected. We further control for the legal and regulatory surrounding which is crucial for the supply side in a capital-intensive network industry. The indices *investment_freedom* and *business_freedom* evaluate a country with respect to a variety of restrictions that are typically imposed on investments and to the efficiency of government regulation of business, respectively. Both measures rate a country on a scale from 0 to 100 with an ideal score of 100. Any economic restrictions on the flow of investment capital and any difficulties in starting, operating, and closing a business are expected to constitute an impediment to broadband deployment and adoption. The positive impact of *business_freedom* on fixed broadband demand, indeed points to the importance of a reliable political and legal environment in industries with largely irreversible investments. As an additional demand control the total national telecommunications revenues measured in logs, *telco_rev*, are included. Higher expenditures mirror higher ICT affinity and are, unsurprisingly, found to increase broadband demand.

Fourth, more attention is paid to the mode of competition and its relation to tariff diversity (Table 8). Besides the finding that price discrimination stimulates demand, there is convincing evidence that competition fosters broadband adoption whereas the exertion of market power hinders it. While market power is often seen as a prerequisite for the existence of price discrimination (Varian 1989; Posner 1976), various papers show that price discrimination and market power are not necessarily positively correlated (see, e.g., Armstrong and Vickers 2001; Borenstein 1985; McAfee et al. 2006). If, however, the former holds, regulators might face a trade-off between the intensity of competition and the extent of tariff diversity.[27] To account for this potential trade-off *inter_high*diversity* is included, where *inter_high* equals 1 if there are DSL, cable, and fiber broadband providers active in country $i$ at period $t$, and 0 otherwise. The results suggest that tariff diversity exerts a positive impact on demand in countries with a distinct level of facilities-based competition, falsifying the hypothesis that a trade-off between competition and tariff diversity exists. The European Commission's intention to cut down the regulation on unbundled access and to promote facilities-

[27] Note that even if price discrimination implies the existence of market power, a high degree of price differentiation does not provide proof that market power is substantial in antitrust trials (e.g., McAfee et al. 2006; McAfee 2008; Klein 2008).

based competition seems therefore to be the appropriate policy for regulators (see, also Bourreau and Doğan 2006).

Fifth, and finally, the estimations in Table 9 account for potential (non-linear) substitution patterns between fixed and mobile broadband, where *mobile* represent the number of mobile subscribers, including all mobile broadband PC or laptop connections via a USB modem or datacard but excluding handset access or use of the handset as a modem.[28] Since there may be common driving factors for fixed and mobile demand, we instrument mobile broadband subscription with its fourth lag and, in order to be interpreted as an elasticity, *mobile* is included in logs. We find a U-shaped relationship and, like Cincera et al. (2014), significant substitution between fixed and mobile broadband on average. Bearing in mind the pronounced fixed-to-mobile substitution in the telephony market, mobile broadband might soon be able to dominate fixed broadband, raising the question of whether any fixed-broadband technologies, including fiber-based broadband which is currently considered the main infrastructure for high-speed internet, can compete with mobile broadband in the long run.

## 4 Conclusion

This paper is the first to use a rich dataset of 10,200 residential broadband plans to study the impact of price differentiation on broadband adoption using longitudinal data. We use a sample of 23 European countries from 2003 to 2011 and apply dynamic panel data techniques while carefully accounting for possible endogeneity problems. The paper contributes in several ways to the research literature. At a methodological level, this article goes beyond the existing literature on price discrimination in the retail broadband market by accounting for several sources of endogeneity, and utilizing GMM estimation methods. Furthermore, we can show that the results of Haucap et al. (2016) are applicable for developed markets alike, that the effect persists over time, and that it is reasonably robust.

Most notably, second-degree price discrimination to segment customers seems to be a means to foster broadband adoption. Demands by some public interest groups to limit price discrimination in broadband markets (see, e.g., Lyons 2013) should therefore be viewed with some caution as reduced price discrimination may come at the cost of a reduced number of subscribers. Regarding the competitive environment, the results suggest that facilities-based competition is a stronger driver of broadband penetration compared to the intensity of service-based competition. Starting from a legacy infrastructure with a sole telephony network, regulation in the EU has aimed at increasing service-based competition. However, it has been shown that with various broadband access technologies available it is inter-platform competition that promotes broadband demand and induces a positive impact of price differentiation on demand. Consequently, the favoritism of service-based competition may be outmoded and policymakers should intensify their focus on facilities-based competition.

[28] Mobile broadband subscription is not part of the baseline specification as its inclusion results in a 20% sample size reduction.

One limitation of this study is that the number of subscribers to a given plan is unknown wherefore unweighted averages for some variables have to be used. However, by including numerous measures for tariff diversity as well as utilizing an instrumental variables approach and several robustness checks, we are able to show that our results are robust. Furthermore, although the analysis is based on broadband demand as an aggregated measure, there is no reason to assume that consumer behavior systematically differs with respect to mobile broadband and NGA demand or any further network enhancements that we are likely to see in the future. In conclusion, this article advances the existing literature in several ways and points to the importance of diversified pricing schemes to foster broadband demand.

## Appendix

See Tables 3, 4, 5, 6, 7, 8 and 9.

**Table 3** Countries

| | | |
|---|---|---|
| Austria; 2003–2011 | Germany; 2003–2011 | Portugal; 2003–2011 |
| Belgium; 2003–2011 | Hungary; 2007–2011 | Romania; 2008–2011 |
| Bulgaria; 2008–2011 | Ireland; 2005–2011 | Slovakia; 2007–2011 |
| Czech Rep.; 2007–2011 | Italy; 2003–2011 | Slovenia; 2007–2011 |
| Denmark; 2003–2011 | Latvia; 2008–2011 | Spain; 2003–2011 |
| Estonia; 2008–2011 | Lithuania; 2008–2011 | Sweden; 2003–2011 |
| Finland; 2003–2011 | Netherlands; 2003–2011 | UK; 2003–2011 |
| France; 2003–2011 | Poland; 2007–2011 | |

**Table 4** Variables description and source

| Variable | Description | Source |
|---|---|---|
| *fbb_sub* | Number of active retail broadband subscribers, including DSL, cable, fiber, and other fixed broadband connections, i.e., satellite, broadband over power lines, and WiMax | Analysys Mason ('Telecoms Market Matrix') |
| *fbb_price* | Unweighted average monthly access charge for fixed broadband internet service per Mbps download speed in euro PPP | Analysys Mason ('Tripleplay pricing study') |
| *diversity_sd* | Standard deviation of access prices for stand-alone fixed broadband offerings | Analysys Mason ('Tripleplay pricing study') |
| *diversity_minmean* | Difference between minimum and mean of access prices for stand-alone fixed broadband offerings | Analysys Mason ('Tripleplay pricing study') |
| *diversity_minmax* | Difference between minimum and maximum of access prices for stand-alone fixed broadband offerings | Analysys Mason ('Tripleplay pricing study') |
| *diversity_admedian* | Average absolute deviation from the median of access prices for stand-alone fixed broadband offerings | Analysys Mason ('Tripleplay pricing study') |
| *diversity_admean* | Average absolute deviation from the mean of access prices for stand-alone fixed broadband offerings | Analysys Mason ('Tripleplay pricing study') |
| *speed* | Unweighted average advertised maximum download speed for fixed broadband connection in Mbps | Analysys Mason ('Tripleplay pricing study') |
| *pc_hh* | Percentage of households with access to a PC over one of its members | Eurostat |
| *gdp_percapita* | Quarterly real GDP per capita in euro PPP | Eurostat |
| *hhi_inter* | Herfindahl-Hirschman Index of DSL, cable, fiber, and other fixed broadband connections | Analysys Mason ('Telecoms Market Matrix') |

**Table 4** continued

| Variable | Description | Source |
|---|---|---|
| *hhi_intra* | Herfindahl-Hirschman Index of incumbent's and entrants' DSL connections | Analysys Mason ('Telecoms Market Matrix') |
| *bundles_share* | Share of bundled offers consisting of any combination of fixed broadband and fixed voice, TV, mobile voice, and mobile data | Analysys Mason ('Tripleplay pricing study') |
| *caps_share* | Share of tariffs with a monthly usage tier | Analysys Mason ('Tripleplay pricing study') |
| *mobile* | Number of mobile broadband subscribers (includes all mobile broadband PC or laptop connections via an USB modem or datacard and excludes handset access or use of the handset as a modem) | Analysys Mason ('Telecoms Market Matrix') |
| *population* | Population size | World Bank |
| *pop_density* | Population density. Inhabitants per sq. km of land area | World Bank |
| *urban* | Share of urban population | World Bank |
| *fms* | Share of fixed landlines (including non-VoIP cable telephony) in the total number of fixed landlines and mobile (pre-paid and post-paid, excluding customers who have not used their mobile account for more than 3 months) telephony subscriptions | Analysys Mason ('Telecoms Market Matrix') |
| *telco_rev* | Telecommunications revenues from fixed landline, mobile, and VoIP telephony plus broadband internet | Analysys Mason ('Telecoms Market Matrix') |
| *cost_cons* | Labor input in construction (gross wages and salaries, $2010=100$) | Eurostat |
| *inter_high* | Dummy variable, equals 1 if there are DSL, cable, and fiber broadband providers active in country $i$ at period $t$, 0 otherwise | Analysys Mason ('Telecoms Market Matrix') |
| *investment_freedom* | Index of Freedom of Investment [0–100] | Heritage Foundation |
| *business_freedom* | Index of Business Freedom [0–100] | Heritage Foundation |

**Table 5** GDP per capita ≥ 7000 euro

| Dependent variable: *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*fbb_sub* | 0.617*** | 0.703*** | 0.613*** | 0.653*** | 0.609*** |
| | (0.056) | (0.054) | (0.080) | (0.040) | (0.044) |
| L.*fbb_price* | − 0.091** | − 0.083*** | − 0.062** | − 0.119*** | − 0.095*** |
| | (0.038) | (0.032) | (0.027) | (0.045) | (0.034) |
| L.*diversity_sd* | 0.067** | | | | |
| | (0.034) | | | | |
| L.*diversity_minmean* | | 0.063** | | | |
| | | (0.028) | | | |
| L.*diversity_minmax* | | | 0.047* | | |
| | | | (0.024) | | |
| L.*diversity_admedian* | | | | 0.088** | |
| | | | | (0.039) | |
| L.*diversity_admean* | | | | | 0.070** |
| | | | | | (0.030) |
| *speed* | − 0.001 | 0.000 | − 0.001 | − 0.001 | − 0.001 |
| | (0.001) | (0.000) | (0.00) | (0.00) | (0.00) |
| *hhi_inter* | − 0.937*** | − 0.924** | − 1.117*** | − 0.670** | − 0.909*** |
| | (0.309) | (0.403) | (0.313) | (0.322) | (0.352) |
| *hhi_intra* | − 0.153 | − 0.053 | − 0.110 | − 0.060 | − 0.153 |
| | (0.130) | (0.102) | (0.173) | (0.127) | (0.113) |
| *fms* | 2.216 | 3.049 | 2.954 | 0.980 | 1.367 |
| | (2.112) | (2.320) | (1.978) | (1.589) | (1.960) |
| *fms_sq* | − 4.938 | − 7.826* | − 7.879** | − 2.761 | − 3.616 |
| | (3.646) | (4.593) | (3.388) | (2.651) | (3.363) |
| *pop_density* | − 0.002 | 0.007 | 0.006 | − 0.002 | − 0.003 |
| | (0.005) | (0.007) | (0.008) | (0.005) | (0.005) |
| *urban* | 0.034 | − 0.028 | − 0.031 | 0.043 | 0.059 |
| | (0.045) | (0.069) | (0.062) | (0.054) | (0.052) |
| *gdp_percapita* | 0.354*** | 0.279*** | 0.335*** | 0.380*** | 0.359*** |
| | (0.126) | (0.088) | (0.098) | (0.140) | (0.136) |
| *pc_hh* | 0.727** | 0.877** | 0.801** | 0.855** | 0.812** |
| | (0.336) | (0.367) | (0.373) | (0.342) | (0.373) |
| *population* | 1.232* | 0.382 | 1.116 | 0.617 | 1.401* |
| | (0.744) | (1.044) | (1.323) | (0.683) | (0.760) |
| *N* | 164 | 164 | 164 | 164 | 164 |
| Sargan test $\chi^2$-stat | 62.51 | 66.26 | 55.16 | 72.14 | 67.51 |

**Table 5** continued

| Dependent variable: *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *p* value | 0.80 | 0.70 | 0.94 | 0.51 | 0.66 |
| AR(4), Prob > *z* | 0.21 | 0.18 | 0.22 | 0.22 | 0.23 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Countries included in this analysis are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Sweden, and the UK
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

**Table 6** Dimensions of fixed broadband plans

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*fbb_sub* | 0.620*** | 0.646*** | 0.621*** | 0.631*** | 0.652*** |
| | (0.061) | (0.077) | (0.063) | (0.062) | (0.061) |
| L.*fbb_price* | − 0.053* | − 0.051* | − 0.038** | − 0.051* | − 0.046 |
| | (0.030) | (0.028) | (0.019) | (0.031) | (0.029) |
| L.*diversity_sd* | 0.041* | | | | |
| | (0.023) | | | | |
| L.*diversity_minmean* | | 0.042* | | | |
| | | (0.024) | | | |
| L.*diversity_minmax* | | | 0.030* | | |
| | | | (0.015) | | |
| L.*diversity_admedian* | | | | 0.039 | |
| | | | | (0.024) | |
| L.*diversity_admean* | | | | | 0.035 |
| | | | | | (0.022) |
| *speed* | − 0.000 | − 0.001 | − 0.000 | − 0.000 | − 0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| *bundles_share* | 0.051 | 0.052* | 0.059* | 0.044 | 0.043 |
| | (0.033) | (0.030) | (0.033) | (0.029) | (0.030) |
| *caps_share* | 0.049** | 0.073*** | 0.051** | 0.046** | 0.050** |
| | (0.025) | (0.021) | (0.023) | (0.022) | (0.024) |
| *hhi_inter* | − 1.037** | − 1.081** | − 1.128*** | − 0.996** | − 0.998** |
| | (0.470) | (0.505) | (0.431) | (0.461) | (0.456) |
| *hhi_intra* | − 0.079 | − 0.051 | − 0.092 | − 0.045 | − 0.066 |
| | (0.132) | (0.138) | (0.135) | (0.121) | (0.119) |
| *fms* | 3.818* | 2.175 | 3.417* | 3.920* | 3.544* |
| | (2.153) | (1.862) | (1.798) | (2.111) | (2.009) |

**Table 6** continued

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *fms_sq* | −7.651** | −5.746* | −7.374** | −7.907** | −7.321** |
| | (3.754) | (3.437) | (3.273) | (3.672) | (3.525) |
| *pop_density* | −0.008 | −0.005 | −0.003 | −0.004 | −0.005 |
| | (0.013) | (0.013) | (0.013) | (0.013) | (0.013) |
| *urban* | 0.046 | 0.038 | 0.019 | 0.038 | 0.046 |
| | (0.034) | (0.045) | (0.034) | (0.031) | (0.031) |
| *gdp_percapita* | 0.286*** | 0.236*** | 0.269*** | 0.304*** | 0.296*** |
| | (0.079) | (0.064) | (0.072) | (0.079) | (0.079) |
| *pc_hh* | 1.328*** | 1.511*** | 1.273*** | 1.225*** | 1.206*** |
| | (0.429) | (0.471) | (0.371) | (0.412) | (0.409) |
| *population* | 1.279 | 0.252 | 0.641 | 1.152 | 0.958 |
| | (1.085) | (0.998) | (0.811) | (1.065) | (1.076) |
| *N* | 301 | 301 | 301 | 301 | 301 |
| Sargan test $\chi^2$-stat | 74.29 | 65.29 | 68.87 | 79.10 | 79.23 |
| *p* value | 0.37 | 0.67 | 0.55 | 0.24 | 0.24 |
| AR(4), Prob > *z* | 0.11 | 0.14 | 0.11 | 0.11 | 0.12 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

**Table 7** Additional cost and demand controls

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*fbb_sub* | 0.591*** | 0.604*** | 0.570*** | 0.590*** | 0.590*** |
| | (0.084) | (0.080) | (0.092) | (0.083) | (0.081) |
| L.*fbb_price* | -0.054** | −0.054* | −0.040** | −0.059* | −0.055* |
| | (0.028) | (0.028) | (0.019) | (0.031) | (0.030) |
| L.*diversity_sd* | 0.038* | | | | |
| | (0.023) | | | | |
| L.*diversity_minmean* | | 0.040* | | | |
| | | (0.023) | | | |
| L.*diversity_minmax* | | | 0.027* | | |
| | | | (0.016) | | |
| L.*diversity_admedian* | | | | 0.041* | |
| | | | | (0.025) | |
| L.*diversity_admean* | | | | | 0.038 |
| | | | | | (0.024) |

**Table 7** continued

| Dependent variable *fbb_sub* | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *speed* | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| *hhi_inter* | −0.888** | −0.925** | −0.913** | −0.875** | −0.861** |
| | (0.372) | (0.398) | (0.383) | (0.370) | (0.359) |
| *intra_hh* | −0.091 | −0.108 | −0.147 | −0.039 | −0.055 |
| | (0.149) | (0.145) | (0.155) | (0.150) | (0.148) |
| *fms* | 1.343 | 1.221 | 0.605 | 2.082 | 1.574 |
| | (1.784) | (1.834) | (1.991) | (1.971) | (1.697) |
| *fms_sq* | −2.403 | −3.328 | −1.661 | −3.700 | −2.813 |
| | (2.849) | (3.157) | (3.236) | (3.435) | (2.790) |
| *urban* | 0.042 | 0.027 | 0.025 | 0.039 | 0.038 |
| | (0.045) | (0.049) | (0.046) | (0.045) | (0.045) |
| *urban*cost_cons* | −0.000 | −0.000 | −0.000 | −0.000 | −0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| *cost_cons* | 0.006 | 0.006 | 0.007 | 0.005 | 0.006 |
| | (0.005) | (0.005) | (0.006) | (0.005) | (0.005) |
| *business_freedom* | 0.003** | 0.003* | 0.003** | 0.003* | 0.003** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| *investment_freedom* | 0.004 | 0.003 | 0.002 | 0.003 | 0.003 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| *gdp_percapita* | 0.130* | 0.122* | 0.130** | 0.142* | 0.134 |
| | (0.076) | (0.066) | (0.063) | (0.083) | (0.083) |
| *pc_hh* | 1.293*** | 1.387*** | 1.412*** | 1.184*** | 1.166*** |
| | (0.440) | (0.456) | (0.453) | (0.415) | (0.396) |
| *population* | 0.778 | 0.458 | 0.711 | 0.934 | 0.788 |
| | (1.198) | (1.040) | (1.263) | (1.077) | (1.140) |
| *telcom_rev* | 0.293* | 0.104 | 0.230 | 0.266 | 0.296* |
| | (0.169) | (0.130) | (0.143) | (0.179) | (0.173) |
| *N* | 292 | 292 | 292 | 292 | 292 |
| Sargan test $\chi^2$-stat | 56.04 | 47.06 | 54.71 | 55.75 | 58.50 |
| *p* value | 0.83 | 0.97 | 0.86 | 0.83 | 0.76 |
| AR(4), Prob > *z* | 0.21 | 0.28 | 0.25 | 0.20 | 0.22 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

**Table 8** Trade-off competition and tariff diversity

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*fbb_sub* | 0.540*** | 0.579*** | 0.564*** | 0.534*** | 0.546*** |
| | (0.085) | (0.096) | (0.088) | (0.088) | (0.084) |
| L.*fbb_price* | − 0.045* | − 0.029* | − 0.028* | − 0.039* | − 0.039* |
| | (0.023) | (0.015) | (0.017) | (0.021) | (0.020) |
| L.*diversity_sd* | 0.020 | | | | |
| | (0.018) | | | | |
| L.*diversity_sd*inter_high* | 0.021** | | | | |
| | (0.010) | | | | |
| L.*diversity_minmean* | | 0.010 | | | |
| | | (0.013) | | | |
| L.*diversity_minmean*inter_high* | | 0.023** | | | |
| | | (0.009) | | | |
| L.*diversity_minmax* | | | 0.014 | | |
| | | | (0.015) | | |
| L.*diversity_minmax*inter_high* | | | 0.014** | | |
| | | | (0.007) | | |
| L.*diversity_admedian* | | | | 0.013 | |
| | | | | (0.017) | |
| L.*diversity_admedian*inter_high* | | | | 0.026** | |
| | | | | (0.012) | |
| L.*diversity_admean* | | | | | 0.012 |
| | | | | | (0.015) |
| L.*diversity_admean*inter_high* | | | | | 0.023** |
| | | | | | (0.010) |
| *speed* | − 0.001 | − 0.001 | − 0.001 | − 0.002 | − 0.001 |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.002) |
| *inter_high* | − 0.019 | − 0.028* | − 0.016 | − 0.024 | − 0.020 |
| | (0.023) | (0.016) | (0.021) | (0.021) | (0.022) |
| *intra_hh* | − 0.009 | − 0.003 | − 0.072 | 0.036 | 0.023 |
| | (0.140) | (0.147) | (0.135) | (0.158) | (0.150) |
| *urban* | 0.041 | 0.024 | 0.024 | 0.036 | 0.041 |
| | (0.050) | (0.046) | (0.043) | (0.057) | (0.053) |
| *business_freedom* | 0.002** | 0.001* | 0.002** | 0.002** | 0.002** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| *investment_freedom* | 0.003 | 0.002 | 0.003 | 0.003 | 0.002 |
| | (0.003) | (0.002) | (0.002) | (0.003) | (0.003) |
| *fms* | 1.704 | 0.437 | 1.256 | 1.296 | 1.470 |
| | (1.352) | (1.577) | (1.389) | (1.693) | (1.508) |

**Table 8** continued

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *fms_sq* | − 3.496 | − 1.673 | − 3.278 | − 2.760 | − 2.932 |
| | (2.411) | (2.892) | (2.594) | (2.982) | (2.625) |
| *gdp_percapita* | 0.264** | 0.224** | 0.252*** | 0.278** | 0.272** |
| | (0.107) | (0.094) | (0.097) | (0.111) | (0.109) |
| *pc_hh* | 0.858*** | 0.861*** | 0.830*** | 0.847*** | 0.829*** |
| | (0.321) | (0.298) | (0.309) | (0.309) | (0.321) |
| *population* | 1.476 | 0.609 | 1.268 | 1.263 | 1.327 |
| | (1.405) | (1.131) | (1.475) | (1.227) | (1.301) |
| *telco_rev* | 0.065 | 0.040 | 0.060 | 0.072 | 0.076 |
| | (0.109) | (0.105) | (0.117) | (0.102) | (0.099) |
| *N* | 301 | 301 | 301 | 301 | 301 |
| Sargan test $\chi^2$-stat | 76.34 | 80.46 | 75.38 | 75.40 | 78.96 |
| *p* value | 0.71 | 0.59 | 0.74 | 0.74 | 0.64 |
| AR(4), Prob > *z* | 0.22 | 0.23 | 0.21 | 0.24 | 0.22 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

**Table 9** Mobile broadband subscription

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*mobile* | − 0.149** | − 0.129** | − 0.134** | − 0.140** | − 0.146** |
| | (0.058) | (0.054) | (0.055) | (0.060) | (0.058) |
| L.*mobile_sq* | 0.005** | 0.004* | 0.004* | 0.004* | 0.004* |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| L.*fbb_sub* | 0.661*** | 0.650*** | 0.652*** | 0.662*** | 0.666*** |
| | (0.066) | (0.063) | (0.062) | (0.066) | (0.067) |
| L.*fbb_price* | − 0.023** | -0.030** | − 0.024** | − 0.024** | − 0.020** |
| | (0.011) | (0.015) | (0.010) | (0.012) | (0.009) |
| L.*diversity_sd* | 0.015* | | | | |
| | (0.009) | | | | |
| L.*diversity_minmean* | | 0.020* | | | |
| | | (0.012) | | | |
| L.*diversity_minmax* | | | 0.016* | | |
| | | | (0.008) | | |
| L.*diversity_admedian* | | | | 0.016* | |
| | | | | (0.009) | |

**Table 9** continued

| Dependent variable *fbb_sub* | | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| L.*diversity_admean* | | | | | 0.012* |
| | | | | | (0.007) |
| *inter_hh* | −0.125 | −0.204 | −0.147 | −0.146 | −0.107 |
| | (0.314) | (0.386) | (0.334) | (0.311) | (0.287) |
| *fms* | −0.090 | 0.634 | 0.598 | −0.070 | −0.141 |
| | (1.232) | (1.148) | (1.129) | (1.159) | (1.163) |
| *fms_sq* | −1.105 | −2.685 | −2.314 | −1.232 | −1.175 |
| | (2.154) | (2.000) | (1.945) | (1.950) | (2.032) |
| *business_freedom* | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| *investment_freedom* | 0.000 | 0.000 | −0.000 | 0.000 | 0.000 |
| | (0.002) | (0.002) | (0.002) | (0.001) | (0.001) |
| *pop_density* | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| *pc_hh* | 0.979*** | 1.061*** | 0.991*** | 0.975*** | 0.989*** |
| | (0.200) | (0.254) | (0.229) | (0.214) | (0.209) |
| *gdp_percapita* | 0.172*** | 0.143*** | 0.158*** | 0.166*** | 0.167*** |
| | (0.047) | (0.043) | (0.043) | (0.047) | (0.047) |
| *population* | 0.298 | 0.200 | 0.397 | 0.199 | 0.241 |
| | (0.631) | (0.636) | (0.651) | (0.617) | (0.619) |
| *N* | 230 | 230 | 230 | 230 | 230 |
| Sargan test $\chi^2$-stat | 101.81 | 107.19 | 102.03 | 106.95 | 104.19 |
| *p* value | 0.15 | 0.08 | 0.15 | 0.08 | 0.11 |
| AR(4), Prob > *z* | 0.22 | 0.22 | 0.26 | 0.23 | 0.23 |

Heteroscedasticity and autocorrelation robust standard errors in parentheses
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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