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Für meine Großmutter
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Chapter 1

General Introduction

This dissertation consists of two parts. Part I includes three empirical essays on different topics in the field of telecommunications economics regarding telephony and broadband internet services. Part II presents an experimental test of a set of predictions unique to a new behavioral theory, namely salience theory, with respect to the domain of consumer choice. The common element among both parts is that we show that not only the price level affects purchase decisions but also the price structure and price expectations influence consumers' choices.

Chapter 2, **Substitution Between Fixed, Mobile, and Voice over IP Telephony – Evidence from the European Union**, co-authored by Amela Saric and published in *Telecommunications Policy*, deals with the European telephony market and its regulation in view of changing consumer behavior towards different telecommunications services. The drastic changes in the industry landscape since the 1990s, when mobile telephony became widespread and fixed network incumbents began providing internet services through the existing copper-based infrastructure, challenge the viability of the regulatory framework as the competitive boundaries might have shifted. In this regard, the analysis of the substitution effects between different types of telephony is the cornerstone of market definition and effective regulation. This chapter explores the access substitution between fixed-lines, mobiles, and managed VoIP in a unified EU cross-country framework. Employing a half-yearly dataset for 20 EU countries for the 2008–2011 period and applying dynamic panel data methods, the analysis demonstrates strong access substitution between fixed-lines and mobiles and provides indicative evidence on the substitution between fixed-lines and VoIP. Overall, evidence is found in favor of access substitution and therefore of joint market definition. Regulatory obligations imposed on the market for access to fixed telephone networks might be redundant.

The two subsequent chapters analyze the determinants of broadband internet adoption with a focus on the impact of tariff diversity, i.e., the differentiation of broadband plans. Ever since broadband 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), substantial efforts have been undertaken by many governments to promote the deployment and adoption of broadband. To achieve the ambitiously set goals, there has been a considerable interest in, first, carving out the influencing determinants for broadband penetration and, second, promoting them across countries. While there is a general consensus that the price level plays an important role, it is from a theoretical perspective less clear how the price variety, i.e., tariff diversity, influences broadband penetration. However, price dispersion within a country has been neglected entirely in the empirical literature.

Broadband customers have been used to choosing from a menu of broadband offerings, varying with respect to down- and upload speeds, contract duration, price structure and possibly bundled services. Differentiation strategies have broadly been accepted as legitimate business strategies and were generally not a matter of policy concern in the past. However, price discrimination has generated a lively debate and many consumer advocates and public interest groups have reacted with skepticism against tendencies to move away from flat rates and to introduce greater tariff diversity (see, e.g., Odlyzko et al., 2012; Lyons, 2013). Contributing to the ongoing debate, chapters 3 an 4 provide an empirical analysis how tariff diversity affects fixed broadband penetration.

Chapter 3, **The Impact of Tariff Diversity on Broadband Penetration – An Empirical Analysis**, is co-authored by Justus Haucap and Ulrich Heimeshoff and published in *Telecommunications Policy.* This chapter provides an empirical analysis how tariff diversity affects fixed broadband penetration based on a cross-sectional dataset for 82 countries worldwide. Given that developing countries are still lagging behind in the digitalization of various fields of society, this analysis focuses on (technologically) developing countries. This is of crucial importance because their shortages should first be addressed in order to bridge the digital divide. To measure tariff diversity on a country-level a detailed dataset comprising over 1000 fixed-line broadband tariffs is used. An instrumental variable approach is applied to estimate demand, controlling for various industry and socio-economic factors. The results indicate that service-related and socio-economic factors affect broadband demand the most. An increase in tariff diversity provides a significant impetus to broadband adoption. A positive relationship is indicative of the importance of innovative pricing schemes in expediting the ascent of broadband internet access.

Chapter 4, **Tariff Diversity and Competition – Drivers for Broadband Adoption in the European Union**, re-examines the findings from the previous chapter using longitudinal data for European countries as dynamic developments could not be taken into account in Chapter 3 and the obtained results may not be applicable to more technologically advanced countries. The empirical analysis is performed using a unique dataset of 10,200 broadband plans spanning the 2003–2011 period and including 23 EU member states. The results confirm that an increase in tariff diversity stimulates 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 lower penetration rates. Regarding the competitive environment, the results suggest that facility-based competition is a stronger driver of broadband penetration than service-based competition. The intention of the European Commission to promote facility-based competition consequently seems to be the appropriate policy for regulators in order to promote broadband adoption.

Part II of this thesis presents an experimental test of a new behavioral theory. By assuming context-dependent choices, salience theory (Bordalo et al., 2012a,b, 2013) can explain a wide range of decision biases in one theoretical framework, making it a promising behavioral meta-theory of individual decision making.

Chapter 5, **Demand Shifts Due to Salience Effects: Experimental Evidence**, is joint work with Markus Dertwinkel-Kalt, Katrin Köhler, and Tobias Wenzel and published in *Journal of the European Economic Association*. We are the first to test the fundamental assumptions of salience theory with respect to decision making between two vertically differentiated products: First, a higher expected price level for the products makes consumers less price sensitive and shifts demand toward the more expensive, high-quality product and, second, demand for the high-quality product is only larger if the price level is expectedly high; otherwise, consumers remain price-sensitive. In the conducted experiment, participants chose between a more expensive, fast internet connection (the high-quality product) and a cheaper, slow internet connection (the low-quality product). In the first two treatments prices were known and either low (LP) or marked up by the same amount (HP). In another treatment subjects were initially unsure about the price level (UHP) but eventually faced the high HP-prices. Our results strongly support both predictions by salience theory which neither rational choice nor theories of loss aversion can account for. We find that (i) the share of subjects opting for the premium product is significantly larger in HP than in LP and (ii) subjects are less likely to choose the high-quality product in UHP than in HP. Our findings, for instance, provide a rationale why suppliers can sustain high margins for premium products in high price environments where quality is more likely to be overweighted while prices tend to be disregarded. Moreover, this study highlights the importance of price expectations for consumers' choices.

Bibliography

Bordalo, P., Gennaioli, N., and Shleifer, A. (2012a). Salience in experimental tests of the endowment effect. *American Economic Review*, 102(3):47–52.

Bordalo, P., Gennaioli, N., and Shleifer, A. (2012b). Salience theory of choice under risk. *Quarterly Journal of Economics*, 127(3):1243–1285.

Bordalo, P., Gennaioli, N., and Shleifer, A. (2013). Salience and consumer choice. *Journal of Political Economy*, 121(5):803–843.

Czernich, N., Falck, O., Kretschmer, T., and Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal*, 121(552):505–532.

ITU and UNESCO (2013). The state of broadband 2013: Universalizing broadband.

Lyons, D. (2013). Internet policy's next frontier: Usage-based broadband pricing. *Federal Communications Law Journal*, 66(1):1–44.

Odlyzko, A., Arnaud, B. S., Stallman, E., and Weinberg, M. (2012). Know your limits: Considering the role of data caps and usage based billing in internet access service. White Paper, Washington, DC: Public Knowledge.

OECD (2008). Broadband growth and policies in OECD countries.

Röller, L.-H. and Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *The American Economic Review*, 91(4):909–923.

Part I

Empirical Economics

Chapter 2

Substitution Between Fixed, Mobile, and Voice over IP Telephony – Evidence from the European Union

Co–authored by Amela Saric

2.1 Introduction

The national telecommunications sectors have in the past operated as natural monopolies. State-owned carriers were in charge of maintaining and providing access to the national copper-based fixed telephone network.[1] The industry landscape began changing in the 1990s, when mobile telephony became widespread due to the deployment of GSM technology. In the same period, fixed network incumbents began providing Internet services through the existing copper-based infrastructure. In one of the first liberalization attempts, the US Telecommunications Act of 1996 imposed access obligations on incumbent carriers to allow for network interconnection. The EU followed suit in 1998. Nowadays, wholesale access obligations still remain in place in most European countries (European Commission, 2014c). The incumbent carriers are required to lease the copper infrastructure to entrants at regulated (usually cost-based) access prices.

Recent developments in the EU telecommunications markets challenge the viability of the existing regulatory framework (Briglauer et al., 2011; Barth and Heimeshoff, 2014a,b). Fixed-line services have been in decline for several years. In contrast, staunch competition in the mobile sector and the resulting price drop have advanced the spread of mobile telephony (European Commission, 2013, p. 63). Broadband coverage is almost universal: at the end of 2013, more than 97% of all EU homes had access to fixed broadband, 62% of which were covered by ultra-fast broadband (European Commission, 2014a). The deployment and uptake of (ultra-)fast broadband provided an impetus for the expansion of VoIP telephony as its quality critically depends on the underlying connection speed.[2] If an emerging com-

[1] The term fixed telephone network is equivalent to Public Switched Telephone Network (PSTN) and Plain Old Telephone Service (POTS). It refers to the international telephone system based on copper wires carrying voice data in the form of analog waves. Fixed telephony includes markets for access, call origination, and call termination on the public telephone network provided at a fixed location.

[2] VoIP, or broadly Internet telephony, is a methodology and a group of technologies that enables the usage of the Internet as the transmission medium for telephone calls. This type of telephony is digital, i.e., voice signals are translated into binary data instead of analog waves. The data packets are then transmitted via Internet Protocol (IP). VoIP can be unmanaged and managed. Unmanaged VoIP (also pure VoIP service, i.e., a peer-to-peer application) is based on a software

munications service such as VoIP becomes a substitute for the existing ones, the competitive boundaries might shift, which has to be considered in the regulatory decision-making.

The European Commission's 'Recommendation on relevant product and service markets within the electronic communications sectors' has recently suggested that *ex ante* access obligations from the markets for access (market 1/2007) and call origination (2/2007) on the public telephone network provided at a fixed location can be removed.[3] While the decision to discontinue the regulation was in the past based on meeting the Three test criteria, national regulators are nowadays obliged to provide evidence that a market has failed the test in order to retain the regulation. The burden of proof has thus been reversed.[4] The decision to deregulate is, inter alia, based on the degree of substitution between fixed-lines and other telephone services (European Commission, 2014c; FICORA, 2013). The Commission underlines that, although both mobiles and VoIP constrain the fixed incumbent carriers, only managed VoIP is a proper substitute for fixed-lines. This conclusion is based on the differences in features, contracts, and consumption patterns between mobile and fixed-line telephony.

Surprisingly, the empirical literature is almost silent with regard to VoIP telephony and its relationship to other communications services. Few existing studies on VoIP examine the traffic substitution and deal almost exclusively with unman-

developed by independent content providers and is not regulated. Typical examples include Skype and Viber. From the demand side, managed VoIP is nearly equivalent to the traditional fixed telephony. Consumers make and receive calls using a telephone gadget and are assigned a geographic or non-geographic number. Termination rates for calls to and from managed VoIP are regulated.

[3] This decision is based on the conclusion that both markets fail the Three criteria test. First, the Commission argues that entry barriers are no longer substantial, given that market entry is possible on the basis of leasing the existing or deploying the own infrastructure. Second, VoIP telephony and mobiles constrain the market power of fixed-line incumbents, with the tendency toward more effective competition in the future. Finally, if *ex ante* access obligations are removed, competition law alone is sufficient to address the remaining market failures.

[4] Currently, markets 1/2007 and 2/2007 have been deregulated in only a few countries. *Ex ante* access obligations have been removed from the market 1/2007 in Finland, Lithuania, Romania, and Slovenia and from the market 2/2007 in Finland and Romania only (European Commission, 2014c). The Netherlands and the UK impose limited remedies on the non-competitive segments (single calls and the ISDN2 and ISDN30 access markets, respectively) of the market 1/2007 (ECORYS, 2013, p.78).

aged VoIP, i.e., peer-to-peer applications. However, analyzing managed VoIP, which is regarded as a possible substitute for a fixed-line due to its similarities from the demand side, is critical in the light of changed market conditions and the necessity to redesign the existing regulatory framework. To the best of our knowledge, a coherent analysis of the access substitutability between fixed-line, mobile and managed VoIP telephony has been absent from the literature. Our paper attempts to bridge this research gap. We address the following questions: (a) what is the extent of access substitution between fixed-lines and managed VoIP? (b) and how is the demand for fixed-lines and managed VoIP affected by mobiles? We focus on access instead of traffic substitution because the former is more relevant from the regulatory perspective and there is a lack of any empirical evidence on this issue.

We employ a half-yearly dataset for 20 EU countries spanning the 2008–2011 period and apply dynamic panel data methods. Our main interest is the estimation of own- and cross-price elasticities between fixed-lines, mobiles, and managed VoIP, which are indicative of the possibility of market power abuse.[5] Our results indicate a strong access substitution between fixed-lines and mobiles and provide vague evidence of their substitution with managed VoIP at the EU level. Second, bundling strategies are essential for maintaining the subscription base in the market for fixed-lines. Contrary to the Commission's appraisal, our findings suggest that fixed-lines and mobiles likely constitute part of the same market. Overall, we find evidence in favor of access substitution and, therefore, of joint market definition. *Ex ante* access obligations imposed on copper-based incumbents might therefore be redundant. However, in the short-run, national regulators might need to consider targeted remedies in order to protect the captive group. In this case, the regula-

[5]Market power abuse by the incumbent carriers in the case of deregulation could lead to unfavorable conditions for consumers (European Commission, 2014b, p.21; BEREC, 2014, pp.15-17; Vodafone, 2014, pp.4-7). This pertains primarily to the captive users, who cannot disconnect from the fixed-lines due to the lack of alternatives. The reasons for the captivity are twofold. First, fixed-lines provide access to services which are not compatible with either VoIP or mobiles, including fax, alarm systems, remote maintenance and monitoring applications. Second, for technical reasons, legacy copper-based equipment cannot always be operated by IP solutions, which creates high switching costs (BEREC, 2014, p.16).

tory framework must be redesigned in a way that is conducive to competition and innovation.

The paper is organized as follows. In Section 2.2, we summarize the relevant literature. Section 2.3 outlines the empirical strategy and describes our dataset. The results are presented in Section 2.4, before the discussion on policy implications in Section 2.5. Finally, Section 2.6 concludes.

2.2 Literature review

A large body of the literature explores traffic and access substitution between fixed-lines and mobiles on both single- and cross-country levels. Studies on VoIP, on the other hand, are scarce and focus only on traffic-level substitution and unmanaged VoIP systems. A detailed literature overview is provided in Tables A2.1 and A2.2 in the Appendix.

The first strand of literature analyzes the substitution between fixed-lines and mobiles on a country level. In one of the pioneering works, Rodini et al. (2003) employ a binary logit model with a US household survey panel data for 2000–2001, documenting access substitution between mobiles and the second fixed-line. Making use of an extended US households survey conducted over the 1999–2001 period, Ward and Woroch (2004) provide evidence of traffic-level substitution. In a related study, Ward and Woroch (2010) employ the same dataset and use a US price subsidy for fixed telephony as a natural experiment in their difference-in-differences analysis. Their results indicate modest access substitution between fixed-lines and mobiles. More recently, Ward and Zheng (2012) provided evidence of access substitution in China, using data for 1998–2007 and applying an Arellano-Bond-type linear dynamic panel model. Employing a logistic model with household survey data for 2004–2009, Suárez and García-Mariñoso (2013) deduce that access substitution between fixed-lines and mobiles in Spain is driven by the type of broadband access, network effects, age, household size and, to a lesser extent, price. Karacuka et al. (2011) analyze the demand for mobile telecommunications services in Turkey. Using operator-level panel data from 2002 to 2006, the authors document strong evidence of traffic-level substitution. The substitution effect is stronger for pre-paid than for post-paid consumers. Briglauer et al. (2011) utilize a sample of Austrian market-level data from 2002 to 2007 to conclude that the demand for fixed-line access is inelastic, while the demand for fixed-line calls is elastic.

The second group of studies employs aggregated cross-country data to explore the relationship between fixed-lines and mobiles. Garbacz and Thompson (2007) estimate a fixed-effects model using a sample of 53 less-developed countries (LDC) from 1996 to 2003. They find that fixed-lines are substitutes in the mobile market, while mobiles may be considered complements in the fixed-line market. Barth and Heimeshoff (2014a,b) employ a dynamic panel data approach in a sample of EU countries, documenting both access and traffic substitution. Other recent studies focus on the role of broadband technologies in fixed-mobile substitution. Using a dataset for 27 EU countries for the 2005–2010 and 2005–2011 period, respectively, Grzybowski (2014) and Grzybowski and Verboven (2016) estimate a discrete choice model of household demand for 'fixed-line only', 'mobile only', and both 'fixed-line and mobile access'. Both studies provide evidence of fixed-mobile substitution. Furthermore, higher fixed broadband penetration is shown to increase the complementarity, while the spread of mobile broadband increases the substitutability between fixed-lines and mobiles. Grzybowski and Verboven (2016) also provide evidence of an incumbency advantage: a dominant position in the fixed-line market can be leveraged into the mobile market.

The second strand of literature analyzes VoIP and its relationship with other telephony services. Most studies analyze individual countries and provide scant econometric evidence on intermodal traffic substitution. Cecere and Corrocher (2011) investigate the usage patterns of mainly unmanaged VoIP services, such as Skype and MSN messenger, by estimating a probit model in a sample of UK consumer survey data from 2006.[6] The authors find that VoIP calls are made more regularly if a household has not subscribed to fixed-line, while the VoIP usage intensity is unaf-

[6] In their dataset, Skype is by far the most popular application with 67% of the respondents using it, followed by MSN (18%), BT/Yahoo! (16%), Tesco (6%), plus Orange (Wanadoo) and Google (both 4%).

fected by the levels of mobile subscription. In contrast, Cecere and Corrocher (2012) use a sample of Italian consumers from 2006 and conclude that mobile telephones negatively affect the usage of unmanaged VoIP. The usage of other IP services (e.g., chat and mail applications), which is associated with deepened IT skills and higher perceived ease of use, slightly increases the probability of using VoIP applications. Unlike the two aforementioned studies, Kwak and Lee (2011) use time-series data from 2006–2009 and employ an instrumental variable approach to analyze the traffic substitution between managed VoIP and other communications services in South Korea.[7] The authors conclude that the usage intensity of managed VoIP is driven by VoIP call rates, fixed-line call rates, and network effects, but is not affected by the pricing of mobile services.

Overall, the literature provides convincing evidence of fixed-mobile substitution on both an access and traffic level, while the evidence on traffic substitution between VoIP and other communications services is inconclusive. The latter is partly due to the relatively old datasets and short time-series. Against this backdrop, our study is the first to investigate the access substitution between VoIP and other communications technologies. We employ a recent dataset and set up a coherent framework for the analysis of the substitution between fixed-lines, mobiles, and managed VoIP.

2.3 Model specification and data

2.3.1 Empirical strategy

A number of studies demonstrate that the subscription and usage patterns of telephony services are characterized by path dependence (Karacuka et al., 2011; Ward and Zheng, 2012; Barth and Heimeshoff, 2014a,b). The reasons for this are twofold. On the one hand, habits and routines thwart prompt adaptation of consumer behavior in the face of changed market conditions. On the other hand, most service

[7]Note that the validity of the instruments included in this study is debatable if the contract length exceeds one month.

contracts are not irrevocable at any time, which precludes their cancellation before the actual expiration date. Following Houthakker and Taylor (1970), we capture the demand persistence using the lagged values of the subscription levels. We further assume that the subscription volumes are driven by both current and lagged prices, since the cancellation and subscription decisions might not be immediate. We specify the demand function for technology $K = \{\textit{fix, mob, voip}\}$ in period t as:

$$k_{sub_t} = f(k_{sub_{t-1}}, p_{k_t}, p_{k_{t-1}}, \mathbf{p}_{k_t}, \mathbf{p}_{k_{t-1}}, X_t),$$

where $k \in K$ denotes fixed, mobile or managed VoIP telephony, k_{sub} is the demand for k measured in terms of the subscription base, p_k is the price of service k, $\mathbf{p}_k = (p_l \mid \forall l \in K_{-k})$ is the price vector of all potential substitutes of k, and X_t is a vector of demand shifters which includes the number of broadband connections, the number of fixed incumbents' subscribers in the mobile market, and the monthly income per capita. Making use of the panel structure of our dataset, we define the demand for service k in country i at time t as:

$$\begin{aligned} k_{sub_{it}} = \alpha + \beta_k k_{sub_{it-1}} + \sum_k \gamma_k p_{k_{it}} + \sum_k \delta_k p_{k_{it-1}} \\ + \sum_k \theta_k X_{k_{it}} + \eta_i + \nu_{it}, \end{aligned}$$

where η_i represents the time-constant country fixed-effect and ν_{it} is an unobservable error term.

Considering that all contracts begin at different points in time and that contractual durations vary, we include the first lag of the dependent variable to capture the average demand persistence. Including a maximum of one lag is a compromise due to the degrees of freedom considerations. According to the economic theory of a downward sloping demand curve, the effect of own price on demand is predicted to be negative. Concerning the prices of other services, a positive coefficient indicates substitutability, while a negative one is indicative of a complementary relationship. The impact of fixed broadband is expected to differ across technologies. First, Grzybowski and Verboven (2016) show that more broadband connections lead to complementarities between fixed and mobile telephony, due to incumbent carriers' ability to leverage their dominant position in the fixed-line network into the mobile market. Second, high-speed broadband ensures a higher quality voice service, thereby providing an impetus for VoIP adoption. Additional bundling strategies and the strategic behavior of fixed-line incumbents are controlled for by accounting for their subscription base in the mobile market.[8] Carriers active in two or more markets are likely to behave strategically by maximizing their joint profit instead of pursuing profit-maximizing behavior in each market separately. This can affect contract features and, ultimately, the individual demand for services. Finally, higher incomes are likely to boost the demand for fixed, mobile, and VoIP telephony.

Given our dynamic setup, we apply the Arellano-Bond Generalized Method of Moments (GMM) estimator (Arellano and Bond, 1991) to address the unobserved heterogeneity and endogeneity issues. Due to the large cross-sectional but small time dimension of our dataset, we choose not to estimate a fixed-effects model, as the demeaning transformation would produce inconsistent estimates (Nickell, 1981). The first-difference transformation of the difference GMM estimator, on the other hand, eliminates the time-constant country fixed-effects and therefore captures one source of endogeneity without leading to inconsistencies. We apply the difference GMM instead of the more efficient system GMM estimator, as the latter is consistent only under the assumption of zero correlation between explanatory variables and individual time-invariant effects (cf. Arellano and Bover, 1995; Blundell and Bond, 1998). Individual time-invariant effects capture a range of unobserved factors, including country-specific consumer preferences, geographic characteristics, and initial infrastructure stock. Each of these variables are correlated with prices and/or subscription levels. For instance, carriers are less able to exploit the economies of scale in countries with mountainous terrain, which probably affects the pricing of the telecommunications services. Furthermore, fixed infrastructure stocks in the 1990s differed substantially across EU countries, which determined future investment and

[8] As a robustness check, we separately control for an incumbent's number of DSL connections, considering that fixed-line telephony is often bundled with copper-based broadband DSL.

consumption patterns (Grzybowski and Verboven, 2016; Grzybowski, 2014). The correlation between explanatory variables and individual time-invariant effects is therefore likely different from zero, implying that the system GMM would be inconsistent.

We estimate the demand using single equation techniques instead of simultaneous multiple equation estimators. The main advantage of system over equation-by-equation estimators is in their efficiency. However, the system estimators are consistent only if all equations are specified correctly. The improved efficiency thus comes at a high cost, since the misspecification in one equation spills over to the estimates of all other equations. Considering that we explore a fairly complex market with substantial differences in the underlying technologies, we choose a single equation estimator which is expected to produce consistent demand estimates.

In our specification, the lagged dependent variable is correlated with the error term and is thus clearly endogenous. Due to unobserved demand shocks, own prices and prices of substitutes are potentially endogenous, too (cf. Caves, 2011). In order to address the endogeneity, we apply an instrumental variable approach. We employ two sets of instruments: (i) lagged levels for lagged dependent and price variables (Arellano and Bond, 1991) and (ii) cost shifters for price variables. The latter group of instruments is valid because costs have no direct impact on subscription decisions, but influence the endogenous price variables. We use the termination rates as cost shifters, as they are directly incorporated into the calling prices and are the only observable cost shifters (cf. Barth and Heimeshoff, 2014a).

Moreover, termination rates are set by the national regulators and are kept constant until the European Commission approves changes after a new round of regulation. Hence, they can be considered exogenous. In line with Briglauer et al. (2011), we include both fixed-to-fixed and fixed-to-mobile termination rates. Since the regulatory changes are likely to affect prices with some delay, we employ their lagged, instead of current, values.

In order to avoid spurious correlations, we test for the presence of a stochastic trend in each variable. The results of the panel unit root test are presented in Table A2.3. Fixed-line and mobile subscriptions are stationary in levels and in differences, whereas VoIP subscription is stationary in differences only. Since the Arellano-Bond GMM estimator is based on differences, our specification does not suffer from spurious correlation problem. Cointegration, i.e., long-term relationship between the variables, cannot be present either, given that the dependent and explanatory variables are integrated of different orders (Hamilton, 1994).

2.3.2 Data

Our dataset comprises 20 EU countries from the second quarter 2008 through the fourth quarter 2011 at six-month intervals.[9] Our main data sources are: Analysys Mason and Eurostat. Data on the subscription levels, prices, number of broadband, DSL, cable, other fixed broadband lines and also mobile broadband connections are retrieved from Analysys Mason. GDP per capita and the consumer price index (CPI) are provided by Eurostat, while population density is taken from the World Bank. Information on fixed-to-fixed and fixed-to-mobile termination rates are from the 'Progress Reports on the Single European Electronic Communication Market' and are supplemented by data from the OECD and the national regulatory authorities where necessary. Table A2.5 provides a detailed description of our dataset.

The regression variables are defined as follows. Fixed-line demand represents the number of active analogue circuit-switched retail subscribers, measured as the number of active channels. Mobile demand is defined as the number of active individual mobile connections, including both pre-paid and post-paid users. Managed VoIP demand refers to the number of active channels of either paid-for native VoIP services that use a broadband access connection or VoIP services included in a paid-for bundle with broadband access. Thus, peer-to-peer applications are excluded. The fixed-line price is expressed as the sum of the access fee and calling price, both calculated as the average revenues per line. As is common in other studies, we proxy for the price of mobile telephony by the average revenue per user (cf., e.g., Ward and Zheng, 2012). The price of VoIP is calculated as the unweighted average price of all double-play contracts, which include both a broadband and a managed

[9]All countries included in this study are listed in Table A2.4 in the Appendix.

VoIP connection. The measure of the average VoIP price might therefore slightly overestimate the actual VoIP price.

In our regression equations, each variable is expressed in logarithms in order to be interpreted as elasticity. The price-related variables are measured in euros and deflated using the CPI with the year 2005 as the base period. Summary statistics are presented in Table 2.1 and the correlation matrix between the variables in Table A2.6.

Table 2.1: Summary statistics

Variable	**Measured in**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
fix_{sub}	Channels	6939906	8382992	315000	29097000	160
mob_{sub}	Active subscribers	27849168	29826034	1658000	106370000	160
$voip_{sub}$	Channels	2055037	4064357	11000	20618000	160
p_{fix}	Euro	35.20	10.43	12.80	70.44	160
p_{mob}	Euro	23.94	7.99	9.41	47.54	160
p_{voip}	Euro	38.11	11.01	10.34	74.63	160
bb_{lines}	Channels	5921575	7248068.868	299000	26902000	160
inc_{mob}	Active subscribers	6524140	11211720	744000	36942060	160
gdp_{pc}	Euro	6489.83	3139.26	1459.79	12618.30	160
inc_{dsl}	Channels	3086100	3979930.308	130000	14191000	160
$cable/other_{bb}$	Channels	1103025	857534.809	113000	3864000	160
$mobile_{bb}$	Active Subscribers	1242321	8884263	12057	39115680	160
pop_{dens}	Inhabitants per km^2	143.422	113.901	22.516	496.389	160
ftr	Euro cents	0.65	0.31	0.01	1.58	160
mtr	Euro cents	6.42	2.75	2	18.82	160

Note: All variables are expressed in levels.

2.4 Empirical results

2.4.1 Main results

The Arellano-Bond GMM estimator is sensitive to the lag structure (e.g., Arellano and Bover, 1995; Blundell and Bond, 1998). Therefore, we estimate two models with different sets of instruments. In Model A, we include the fourth lags of the subscription levels and prices. As our dataset is of half-yearly frequency and some contracts have a 24-months duration, this specification should not suffer from the endogeneity problem. Considering that most contracts are shorter than 24 months, Model B employs the second and the third lag of the dependent variable and the second lag of price variables as instruments.[10] Estimation results from our baseline specification are presented in Table 2.2.

Due to the first-difference transformation of the GMM estimator, the residuals have a moving average structure and are possibly first-order autocorrelated. Autocorrelation AR(s) of a higher-order would imply that the s-th lag of the dependent variable is endogenous, and consequently not a valid instrument. For Model A, the Arellano-Bond test indicates no presence of fourth-order autocorrelation. Hence, the instruments can be considered valid. For Model B, the test rejects the presence of autocorrelation of a higher-order except for the mobile market, implying second-order autocorrelation.[11] We further test for the exogeneity of the instruments by applying the Sargan-Hansen's J test. With p-values ranging from 0.33 to 0.68, the test statistics indicate that the null hypothesis of valid over-identifying restrictions cannot be rejected in either regression.

The results of the fixed-line demand estimation are presented in column (1) for Model A and in column (4) for Model B. The lagged subscription volume has a highly positive impact on contemporaneous demand, implying that a large share of current subscribers do not cancel their contracts in the next period. The demand for fixed-lines is therefore path-dependent. The current own-price elasticity is negative and is within the inelastic range (-0.308 and -0.316). The lagged own-price elasticity is insignificant in Model A but significant in Model B, indicating some long-run price effect on the demand for fixed-line access. The current and the lagged mobile prices are positive and significant, implying substitution from fixed-lines to mobiles.

[10] Our pricing data shows that, on average, 82% of all double-play offers with fixed-lines and broadband have a contract length up to 18 months and 72% up to 12 months. Concerning the double-play offers consisting of VoIP and broadband, 79% of contracts are up to 18 months long, while 72% are up to 12 months long. Concerning the mobile market, around 50% of subscribers use the prepaid services with no contractual obligations.

[11] Given that we apply an equation-by-equation estimation, the fixed-line and VoIP estimation are unaffected by this potential inconsistency in the mobile telephony equation. Note further that the estimation results also hold if only the third lag is included. Hence, the bias is probably small.

Table 2.2: Estimation Results

	Model A			Model B		
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. variable	$fix_{sub_{it}}$	$mob_{sub_{it}}$	$voip_{sub_{it}}$	$fix_{sub_{it}}$	$mob_{sub_{it}}$	$voip_{sub_{it}}$
$fix_{sub_{it-1}}$	0.777***			0.813***		
	(0.109)			(0.068)		
$mob_{sub_{it-1}}$		0.436**			0.516***	
		(0.195)			(0.161)	
$voip_{sub_{it-1}}$			0.940***			0.658***
			(0.071)			(0.084)
$p_{fix_{it}}$	-0.308*	0.151*	-0.197	-0.316***	0.140**	0.247
	(0.157)	(0.082)	(0.592)	(0.119)	(0.072)	(0.440)
$p_{fix_{it-1}}$	-0.246	0.146	-0.412	-0.220*	0.107	0.998**
	(0.172)	(0.113)	(0.404)	(0.127)	(0.104)	(0.497)
$p_{mob_{it}}$	0.268***	-0.220*	0.510	0.234***	-0.264**	-0.136
	(0.100)	(0.126)	(0.407)	(0.067)	(0.109)	(0.334)
$p_{mob_{it-1}}$	0.178*	-0.020	0.327	0.138*	0.074	-0.616
	(0.104)	(0.082)	(0.326)	(0.079)	(0.059)	(0.402)
$p_{voip_{it}}$	-0.018	-0.039*	-0.185***	-0.012	-0.033*	-0.241**
	(0.031)	(0.022)	(0.064)	(0.019)	(0.017)	(0.109)
$p_{voip_{it-1}}$	-0.031	0.008	0.081	-0.024	0.015	-0.039
	(0.019)	(0.020)	(0.116)	(0.019)	(0.023)	(0.087)
$bb_{lines_{it}}$	0.031	-0.020	0.222	0.016	-0.030	0.635**
	(0.111)	(0.088)	(0.245)	(0.107)	(0.078)	(0.305)
$inc_{mob_{it}}$	0.237**	0.067	0.650**	0.204**	0.069	-0.009
	(0.104)	(0.116)	(0.303)	(0.103)	(0.112)	(0.217)
$gdp_{pc_{it}}$	-0.014	0.140***	-0.240*	0.004	0.156***	-0.222
	(0.049)	(0.040)	(0.144)	(0.033)	(0.033)	(0.198)
N	120	120	120	120	120	120
Sargan Test (χ^2)	16.15	17.42	13.80	25.21	22.63	27.59
p-value	0.51	0.43	0.68	0.45	0.60	0.33
AR(2), Prob> z				0.77	0.01	0.42
AR(3), Prob> z				0.13	0.32	0.59
AR(4), Prob> z	0.28	0.15	0.79			

Significance levels *: 10% **: 5% ***: 1%. Heteroscedasticity robust standard errors in parentheses.
We instrument the lagged dependent and all price variables with their corresponding lags and cost shifters. Sargan test: H0: Overidentifying restrictions are valid. AR test: H0: No autocorrelation.

This result is in line with the existing literature and with the overall trends in telecommunications markets, which indicate an increasing importance of mobiles at the expense of fixed telephony. Surprisingly, the impact of VoIP prices on the demand for fixed-lines is insignificant at the aggregate EU level. Managed VoIP might nonetheless restrict the fixed-line carriers with the threat of potential market entry. This threat is credible due to an increasing availability of (ultra-)fast broadband, which fosters the transition from copper- to IP-based networks. We find a positive and significant effect of the number of fixed incumbents' subscribers in the mobile market. The ability to offer bundles constitutes an important factor in maintaining the subscription base and, ultimately, in slowing down the decay of fixed telephony. The number of broadband lines and monthly income per capita are insignificant. The former might be due to the declining market shares of copper incumbents in the broadband market, while the latter indicates that the demand for fixed-lines is primarily determined by the development of a fixed-network infrastructure.

The results of mobile demand estimation are presented in columns (2) and (5). The lagged subscription volume has a positive and significant effect on the contemporaneous demand (+0.436 vs. +0.516). The current own-price elasticity is negative (-0.220 and -0.264), while the lagged own-price elasticity is insignificant. The current cross-price elasticities of mobiles with respect to fixed-lines are positive and significant in both models, providing evidence of fixed-mobile access substitution. A price increase of fixed-lines by 1% increases the demand for mobile telephony by 0.14–0.15%, implying that consumers respond to higher fixed-line prices by shifting away to mobiles. Mobile telephony therefore constrains the market power of fixed-line carriers. The current cross-price elasticity of mobiles with respect to VoIP is negative and significant (-0.039, -0.033), which is indicative of the complementarity between the technologies. The spread and higher affordability of VoIP might have increased the range of the communications options and slightly boosted the adoption of mobiles. However, given a high penetration and the affordability of mobiles in the EU, small price changes in VoIP services are unlikely to alter the mobile demand significantly. The variable number of broadband lines and the number of fixed incumbents' subscribers in the mobile market are insignificant, while the income per capita has a positive and significant effect on mobile demand.

Analogously to fixed-lines and mobiles, managed VoIP demand exhibits strong path dependence (columns 3 and 6). The own-price elasticity is negative (-0.185 and -0.241), while the lagged own-price elasticity is insignificant. The lagged cross-price elasticity of VoIP with respect to fixed-line telephony is positive and significant in Model B. Given the strong advocacy of the European Commission for the joint market definition for VoIP and fixed-lines, substitutability between the two services should be expected. However, the evidence is not very robust. The cross-price elasticities of VoIP with respect to mobiles are insignificant, indicating a one-way complementary relationship. We find a positive effect of the number of fixed-broadband lines on the demand for VoIP access. This effect may be due to VoIP being provided as a cheap add-on to broadband connections and the fact that (ultra-)fast broadband increases voice quality and thereby the attractiveness of IP-based communication services. Moreover, we document a positive impact of the incumbent's subscription base in the mobile market on VoIP access demand. Overall, the analysis provides evidence of incumbents' ability to leverage their dominant position in one market to another by offering bundles of fixed-mobile or VoIP-mobile telephony. This underlines the importance of bundling strategies in the telecommunications industry.

2.4.2 Robustness checks

We assess the robustness of our results by employing two additional specifications.[12] The lag structure in both robustness checks is equivalent to Model A, since the corresponding specification in Model B might induce a bias in mobile demand equation. The first specification (Model C) is in the spirit of Grzybowski (2014) and Grzybowski and Verboven (2016). We decompose the variable number of broadband lines into cable and other fixed broadband (including fibre) and mobile broadband. Additionally, we account for the effect of bundling the copper-based DSL broad-

[12] As a further robustness check, we included a linear and a quadratic trend. Since both variables are insignificant and the results remain unchanged, we do not report the results.

band with fixed-lines by including the number of incumbents' active DSL lines. In the second specification (Model D), we interact the VoIP price with the number of broadband lines. Higher broadband penetration expands the potential VoIP market, thereby raising the demand for VoIP access. Given that the coverage and quality of fixed-line networks in developed and more densely populated countries tend to be more advanced, while the usage of telecommunications services is likely more intensive, both specifications include GDP per capita and population density (cf., e.g., Caves, 2011; Barth and Heimeshoff, 2014a). The results of the robustness checks are presented in Table A2.7.

Both specifications confirm our main results. We document path dependencies in the subscription patterns for each telephony service and a strong substitution from fixed-lines to mobiles. Again, fixed-mobile substitution is weakened by bundling strategies: the presence of fixed-line carriers in the mobile market and/or increased number of incumbents' DSL subscribers in the broadband market help maintain the fixed-line subscription base. The results also confirm the complementarity between mobile and VoIP telephony, as well as the positive relationship between income and the adoption of mobiles. The current own-price elasticity of VoIP demand is significant. However, the same does not hold for cross-price elasticities.

2.5 Policy implications and discussion

The key advantage of our estimation approach is the possibility to disentangle short- and long-run elasticities.[13] Table 2.3 presents own- and cross-price elasticities for fixed, mobile, and VoIP telephony. The estimated short-run elasticities are comparable in magnitude to those from other single- and cross-country studies. However, the long-run elasticities exceed previous estimates (Barth and Heimeshoff, 2014a; Karacuka et al., 2011; Briglauer et al., 2011). This is likely due to the structure of our dataset, which spans a relatively recent period and enables us to capture "the

[13] In the Houthakker-Taylor model, the short-run elasticities are directly estimated as γ_k and the long-run elasticities are determined by $(\gamma_k + \delta_k)/(1 - \beta_k)$.

latest and arguably most dramatic developments" in the telecommunications sector (Vogelsang, 2010, p.14).

Table 2.3: Short- and long-run own-price elasticities

		Model A			Model B		
		fix_{sub}	mob_{sub}	$voip_{sub}$	fix_{sub}	mob_{sub}	$voip_{sub}$
Short-run:	fix_{sub}	-0.308	0.268		-0.316	0.234	
	mob_{sub}	0.151	-0.220	-0.039	0.140	-0.264	-0.033
	$voip_{sub}$			-0.185			-0.241
Long-run:	fix_{sub}	-1.381	2.000		-2.866	1.989	
	mob_{sub}	0.268	-0.390	-0.069	0.289	-0.545	-0.068
	$voip_{sub}$			-3.083	2.918		-0.705

Large long-run demand elasticities raise the question of market definition for voice services. A well-established market delineation approach is the SSNIP test, which compares the estimated long-run own-price elasticities with the critical elasticity ϵ_c. The SSNIP test identifies the smallest relevant market within which a hypothetical monopolist could profitably raise its price while retaining the current subscription base. If the estimated own-price elasticity exceeds ϵ_c, a price increase would lead to lower profits, indicating that the next best substitute has to be included in the market. In line with Vogelsang (2010) and Briglauer et al. (2011), we define the critical elasticity as $\epsilon_c = 1/[m + t]$, where $m = [p - c]/c$ is the price-cost margin and t denotes a "small but significant non-transitory increase in prices", usually 5–10% during a period of 1–2 years. Assuming that the price-cost margin for fixed-line access is $m = 0.5$ (Stumpf, 2007) and that t takes the value of either 0.05 or 0.1, the critical elasticity falls within the range $\epsilon_c = [-1.82, -1.67]$. The estimated fixed-line elasticity from Model A of -1.38 is below this threshold, while the one estimated from Model B is -2.87 and clearly exceeds ϵ_c. Estimates from the robustness checks are the closest to those from Model B, implying that the own-price elasticities are around 2 in absolute value. Fixed-line telephony can therefore be considered to be part of the same market as mobile and managed VoIP access services at the EU level. Cross-country estimates suggest that the competitive pressure from other services appears sufficient to restrain the incumbent carriers, supporting the European Commission's decision to remove the *ex ante* access obligations from the markets 1/2007 and 2/2007.

Overall, our results provide evidence of the substitution from fixed-lines to mobiles and vice versa and are in line with the existing literature. Mobile operators exert competitive pressure on fixed-line carriers, which diminishes the possibility of market power abuse. The magnitude of the long-run cross-price elasticities between fixed-lines and managed VoIP (+2.918) hints at access substitution toward VoIP, but this effect is not robust. However, considering that our dataset does not cover the post–2011 period and that the access is generally less elastic than the usage, our result is in line with the existing literature on VoIP. Vague evidence of access substitution might be due to the fact that a bulk of subscribers do not switch because of price differences, but are automatically transferred from fixed to VoIP services with the provider's transition to an all IP-based network (ECORYS, 2013, p.195). The threat of potential market entry is nonetheless likely to constrain the price-setting behavior of fixed incumbent carriers. In contrast, the ability to offer service bundles underlines a possible source of market power: if consumers perceive bundles as being superior to single services, carriers providing access to the latter may be in a disadvantageous position. National regulators could therefore consider targeted access obligations to ensure a level playing field for all operators in the market. However, considering the differences in competitive conditions across the member states, this issue must be addressed by each national regulatory authority separately.

Another relevant issue for future regulation is the role of unmanaged VoIP. Most national regulators do not consider this service to be a substitute for managed VoIP, which is due to differences in features and consumption patterns. However, an increased usage of unmanaged VoIP might diminish the relevance of other communications services. Future market definition will consequently depend on a range of factors, including (ultra-)fast broadband penetration, quality of service, pricing, and the possibility of receiving calls according to domestic or international numbering plans (European Commission, 2014b). On the other hand, providers might block or degrade the over-the-top (OTT) applications which have the potential to erode their revenues. A blockage, however, is likely to be limited in scope, due to the large countervailing power of major OTT applications such as Skype, Facebook, and

Viber. Therefore, instead of pursuing a full-scale regulation, it might be possible to deal with this issue under competition law (ECORYS, 2013, p.153).

2.6 Conclusion

In this paper, we estimate the degree of access substitution between fixed, mobile, and managed VoIP telephony. Our study is the first to investigate the interdependencies between all three types of voice services in a coherent cross-country framework. We use a sample of 20 EU countries in 2008–2011 and apply dynamic panel data techniques to estimate the own- and the cross-price elasticities. Due to the endogeneity of the lagged subscription base and price variables, we apply an instrumental variable approach.

We document strong access substitution between fixed-lines and mobiles and find weak support for the long-run substitution from fixed-lines to managed VoIP telephony. Hence, both telephone services likely constrain the market power of fixed incumbent carriers. On the other hand, bundling raises the demand for fixed-lines. While the substitutability indicates that *ex ante* access obligations imposed on fixed incumbents might be redundant, bundling strategies as a source of market power hint at their necessity. At the EU level, we find evidence in favor of joint market definition and, therefore, of discontinuing the regulation. However, due to different competitive environments across the member states, this issue must be addressed by the individual national regulators. Thus, the question of whether the threat of market power abuse by the fixed incumbents still exists is not answered conclusively. Targeted access obligations might be one of the solutions to protect the captive group of consumers and ensure a level playing field for all operators active in the market. In this case, national regulators must redesign the regulatory frameworks in a way that does not stifle competition and innovation.

In its explanatory note on the deregulation of markets for access and call origination on the public fixed network, the European Commission underlines that (managed) VoIP, and not mobile, is a proper substitute for fixed-lines. Our results, in contrast, suggest a stronger substitutability between fixed-lines and mobiles than between fixed-lines and VoIP telephony. Given its forward-looking perspective, the Commission anticipates that fixed-lines and VoIP will become effective substitutes within the validity period of the Recommendation. Considering the existence of various "white" and "grey spots" in the EU countries with limited ultra-fast broadband coverage, and the fact that its adoption is path-dependent and therefore somewhat sluggish, this assessment might be too optimistic. Therefore, further research on the substitutability between telephony services with more recent data is necessary to evaluate the effects of regulatory changes. As several fixed incumbent carriers have announced a full-IP transition in upcoming years, this matter might be resolved in the near future.

Bibliography

Arellano, M. and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, 58(2):277–297.

Arellano, M. and Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, 68(1):29–51.

Barth, A.-K. and Heimeshoff, U. (2014a). Does the growth of mobile markets cause the demise of fixed networks? – Evidence from the European Union. *Telecommunications Policy*, 38(11):945–960.

Barth, A.-K. and Heimeshoff, U. (2014b). How large is the magnitude of fixed-mobile call substitution? Empirical evidence from 16 European countries. *Telecommunications Policy*, 38(8-9):771–782.

BEREC (2014). BEREC's Opinion on the Commission Recommendation on relevant product and service markets susceptible to ex ante regulation. Bor(14)71.

Blundell, R. and Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1):115–143.

Briglauer, W., Schwarz, A., and Zulehner, C. (2011). Is fixed-mobile substitution strong enough to de-regulate fixed voice telephony? Evidence from the Austrian markets. *Journal of Regulatory Economics*, 39(1):50–67.

Caves, K. W. (2011). Quantifying price-driven wireless substitution in telephony. *Telecommunications Policy*, 35(11):984–998.

Cecere, G. and Corrocher, N. (2011). The intensity of VoIP usage in Great Britain: Users' characteristics and firms' strategies. *Telecommunications Policy*, 35(6):522–531.

Cecere, G. and Corrocher, N. (2012). The adoption of internet calling among consumers in Italy: An empirical analysis. *Technological Forecasting and Social Change*, 79(3):570–578.

ECORYS (2013). Future electronic communications markets subject to ex-ante regulation. Final Report, Rotterdam.

European Commission (2013). Digital agenda scoreboard 2013. https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/DAE%20SCOREBOARD%202013%20-%20SWD%202013%20217%20FINAL.pdf, European Commission, Brussels.

European Commission (2014a). Digital Agenda Scoreboard 2014 - Trends in European broadband markets. http://ec.europa.eu/digital-agenda/en/news/scoreboard-2014-trends-european-broadband-markets-2014, European Commission, Brussels.

European Commission (2014b). Explanatory Note - Accompanying the document Commission Recommendation on relevant product and service markets within the electronic communications sector susceptible to ex ante regulation in accordance with Directive 2002/21/EC of the European Parliament and of the Council on a common regulatory framework for electronic communications networks and services. SWD(2014)298, European Commission, Brussels.

European Commission (2014c). Implementation of the EU regulatory framework for electronic communications - 2014. C(2007)5406, European Commission, Brussels.

FICORA (2013). Ex ante regulation of call origination on fixed telephone networks removed.

Garbacz, C. and Thompson, H. G. (2007). Demand for telecommunication services in developing countries. *Telecommunications Policy*, 31(5):276–289.

Grzybowski, L. (2014). Fixed-to-mobile substitution in the European Union. *Telecommunications Policy*, 38(7):601–612.

Grzybowski, L. and Verboven, F. (2016). Substitution between fixed-line and mobile access: The role of complementarities. *Journal of Regulatory Economics*, 49(2):113–151.

Hamilton, J. D. (1994). *Time Series Analysis.* Princeton University Press.

Houthakker, H. S. and Taylor, L. S. (1970). Consumer demand in the United States. Harvard University Press, Cambridge, MA.

Karacuka, M., Haucap, J., and Heimeshoff, U. (2011). Competition in Turkish mobile telecommunications markets: Price elasticities and network substitution. *Telecommunications Policy*, 35(2):202–210.

Kwak, J. H. and Lee, B. G. (2011). Estimating demand curve in the Korean VoIP telecommunications market. *Technological Forecasting and Social Change*, 78:713–728.

Lange, M. R. J. and Saric, A. (2016). Substitution between fixed, mobile, and Voice over IP telephony – Evidence from the European Union. *Telecommunications Policy*, 40(10-11):1007–1019.

Nickell, S. J. (1981). Biases in dynamic models with fixed effects. *Econometrica*, 49(6):1417–1426.

Rodini, M., Ward, M. R., and Woroch, G. A. (2003). Going mobile: Substitution between fixed and mobile access. *Telecommunications Policy*, 27(5–6):457–476.

Stumpf, U. (2007). Regulatory approach to fixed-mobile-substitution, bundling and integration. WIK Discussion paper 290, Bad Honnef.

Suárez, D. and García-Mariñoso, B. (2013). Which are the drivers of fixed to mobile telephone access substitution? An empirical study of the Spanish residential market. *Telecommunications Policy*, 37(4-5):282–291.

Vodafone (2014). Vodafone response to the European Commission consultation on the review of relevant markets.

Vogelsang, I. (2010). The relationship between mobile and fixed-line communications: A survey. *Information Economics and Policy*, 22(1):4–17.

Ward, M. R. and Woroch, G. A. (2004). Usage substitution between mobile telephone and fixed line in the US. mimeo, Arlington.

Ward, M. R. and Woroch, G. A. (2010). The effect of prices on fixed and mobile telephone penetration: Using price subsidies as natural experiments. *Information Economics and Policy*, 22(1):18–32.

Ward, M. R. and Zheng, S. (2012). Mobile and fixed substitution for telephone service in China. *Telecommunications Policy*, 36(4):301–310.

Appendix

Table A2.1: Fixed-mobile substitution studies

Author	Country & Period	Method	Main results
Rodini et al. (2003)	US, 2000–2001	Logit	Moderate access substitution between the second fixed-line and mobile, cross-price elasticity 0.13–0.18.
Ward and Woroch (2004)	US, 1999–2001	LA/AIDS	Moderate fixed-mobile traffic substitution, cross-price elasticity 0.22–0.33.
Ward and Woroch (2010)	US, 1999–2001	Probit/diff-in-diff	Access substitution between the first fixed-line and mobile, cross-price elasticity 0.25–0.31.
Ward and Zheng (2012)	China, 1998–2007	Dynamic panel	Strong fixed-mobile access substitution (FMAS).
Karacuka et al. (2011)	Turkey, 2002–2006	Dynamic panel	Fixed-to-mobile traffic substitution.
Suárez and García-Mariñoso (2013)	Spain, 2004–2009	Logit	Low FMAS. Substitution driven by the broadband connection and socio-demographic characteristics.
Briglauer et al. (2011)	Austria, 2002–2007	Error correction model	Fixed-to-mobile traffic substitution, long-run cross-price elasticity 0.45.
Garbacz and Thompson (2007)	53 LDC, 1996–2003	Fixed-effects	Fixed-lines are substitutes in the mobile market, but mobiles are complements to fixed-lines.
Barth and Heimeshoff (2014a)	EU–27, 2003–2009	Dynamic panel	FMAS, cross-price elasticity 0.18.
Barth and Heimeshoff (2014b)	EU-16, 2004–2010	Dynamic panel	Fixed-to-mobile traffic substitution, cross-price elasticity 0.12.
Grzybowski (2014)	EU, 2005–2010	Discrete choice	FMAS reduced by higher broadband penetration and boosted by the spread of cable and 3G broadband.
Grzybowski and Verboven (2016)	EU, 2005–2011	Discrete choice	FMAS; incumbency advantage in the mobile market; broadband Internet (mainly DSL) reduces substitutability.

Table A2.2: VoIP studies

Author	Country & Period	Method	Main results
Cecere and Corrocher (2011)	UK, 2006	Probit	Traffic substitution between (mainly) unmanaged VoIP and fixed-line. No relationship between mobile and VoIP usage.
Cecere and Corrocher (2012)	Italy, 2006	Probit	Traffic substitution between mobile and unmanaged VoIP. Use of other IP services increases VoIP usage.
Kwak and Lee (2011)	South Korea, 2006–2009	Static panel	Traffic substitution between fixed-lines and managed VoIP, cross-price elasticity 10.07. Mobile-VoIP traffic substitution insignificant.

Table A2.3: Maddala-Wu unit root tests

	Levels		**Differences**	
	χ^2	$\chi^2 > p$	χ^2	$\chi^2 > p$
fix_{sub}	58.889	0.027	58.398	0.030
mob_{sub}	53.976	0.069	62.191	0.014
$voip_{sub}$	45.219	0.263	66.987	0.005
p_{fix}	87.787	0.000	88.058	0.000
p_{mob}	82.628	0.000	62.259	0.014
p_{voip}	120.055	0.000	74.645	0.001
bb_{lines}	269.162	0.000	31.668	0.824
inc_{mob}	93.855	0.000	53.346	0.077
gdp_{pc}	22.544	0.988	64.218	0.009
inc_{dsl}	267.227	0.000	98.737	0.000
$cable/other_{bb}$	36.206	0.642	64.756	0.008
$mobile_{bb}$	26.654	0.948	35.874	0.657
pop_{dens}	44.469	0.2891	68.105	0.004
mtr	106.982	0.000	179.420	0.000
ftr	117.979	0.000	114.546	0.000

H0: unit root.

Table A2.4: Countries

Austria	Ireland	Sweden	Latvia
Belgium	Italy	UK	Poland
Denmark	Netherlands	Bulgaria	Romania
France	Portugal	Estonia	Slovakia
Germany	Spain	Hungary	Slovenia

Table A2.5: Variables description and source

Variable	Description	Source
fix_{sub}	Number of active circuit-switched retail subscribers.	Analysys Mason*
mob_{sub}	Number of mobile (pre-paid and post-paid) subscribers.	Analysys Mason
$voip_{sub}$	Number of active users of either paid-for native VoIP subscribers or VoIP services included in a paid-for bundle with broadband access; excluding peer-to-peer applications.	Analysys Mason
p_{fix}	Average revenue (subscription + traffic) per fixed-line in euro PPP.	Analysys Mason
p_{mob}	Average revenue per mobile subscriber in euro PPP.	Analysys Mason
p_{voip}	Average price of broadband contracts bundled with VoIP in euro PPP.	Analysys Mason ('Triple-play pricing study')
bb_{lines}	Number of active broadband lines.	Analysys Mason
inc_{mob}	Fixed-line incumbent's share in mobile market (in terms of subscribers).	Analysys Mason
gdp_{pc}	Monthly real GDP per capita in euro PPP.	Eurostat
inc_{dsl}	Incumbent's number of DSL broadband subscribers (including ADSL, SDSL and VDSL).	Analysys Mason
$cable/other_{bb}$	Sum of cable and other fixed broadband subscribers (including cable, FTTB, FWA and all other fixed broadband connections).	Analysys Mason
$mobile_{bb}$	Number of mobile broadband PC or laptop connections via a USB modem or datacard. Excludes handset access or use of the handset as a modem.	Analysys Mason
pop_{dens}	Population density. Inhabitants per sq. km of land area.	World Bank
ftr	Fixed-to-fixed termination rates in euro PPP.	Progress Reports on Single European Electronic Communications Markets
mtr	Fixed-to-mobile termination rates in euro PPP.	Progress Reports on Single European Electronic Communications Markets

* If not otherwise indicated, data is from 'Telecoms Market Matrix'.

Table A2.6: Cross-correlation table

Variables	fix_{sub}	mob_{sub}	$voip_{sub}$	p_{fix}	p_{mob}	p_{voip}	bb_{lines}	inc_{mob}
fix_{sub}	1.000							
mob_{sub}	0.911*	1.000						
$voip_{sub}$	0.479*	0.542*	1.000					
p_{fix}	-0.139*	-0.094	-0.010	1.000				
p_{mob}	0.187*	0.014	0.205*	0.498*	1.000			
p_{voip}	0.006	0.027	0.063	0.473*	0.587*	1.000		
bb_{lines}	0.872*	0.924*	0.743*	-0.085	0.149*	0.058	1.000	
inc_{mob}	0.892*	0.971*	0.628*	-0.047	0.105	0.118	0.913*	1.000
gdp_{pc}	0.214*	0.191*	0.267*	0.434*	0.755*	0.557*	0.321*	0.245*
inc_{dsl}	0.890*	0.947*	0.728*	-0.056	0.176*	0.114	0.978*	0.953*
$cable/other_{bb}$	0.205*	0.368*	0.299*	0.058	-0.148*	0.045	0.408*	0.348*
$mobile_{bb}$	0.627*	0.766*	0.459*	-0.118	-0.038	0.077	0.754*	0.726*
pop_{dens}	0.260*	0.316*	0.183*	0.392*	0.237*	0.389*	0.365*	0.315*
ftr	-0.413*	-0.400*	-0.271*	-0.038	-0.179*	-0.041	-0.406*	-0.396*
mtr	-0.063	-0.147*	-0.218*	0.043	0.167*	-0.032	-0.221*	-0.105

	gdp_{pc}	inc_{dsl}	$cable/other_{bb}$	$mobile_{bb}$	pop_{dens}	ftr	mtr
gdp_{pc}	1.000						
inc_{dsl}	0.323*	1.000					
$cable/other_{bb}$	0.157*	0.327*	1.000				
$mobile_{bb}$	0.270*	0.710*	0.379*	1.000			
pop_{dens}	0.376*	0.348*	0.448*	0.169*	1.000		
ftr	-0.283*	-0.390*	-0.164*	-0.384*	-0.142	1.000	
mtr	-0.185*	-0.147*	-0.364*	-0.410*	-0.010	0.284	1.000

$*$: Significant at 5% level or higher.

Table A2.7: Robustness checks

	Model C			Model D		
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. variable	$fix_{sub_{it}}$	$mob_{sub_{it}}$	$voip_{sub_{it}}$	$fix_{sub_{it}}$	$mob_{sub_{it}}$	$voip_{sub_{it}}$
$fix_{sub_{it-1}}$	0.737***			0.790***		
	(0.103)			(0.105)		
$mob_{sub_{it-1}}$		0.581***			0.370**	
		(0.208)			(0.183)	
$voip_{sub_{it-1}}$			1.016***			0.977***
			(0.102)			(0.080)
$p_{fix_{it}}$	-0.203*	0.129	0.141	-0.277*	0.129*	-0.121
	(0.122)	(0.089)	(0.711)	(0.156)	(0.078)	(0.692)
$p_{fix_{it-1}}$	-0.270**	0.081	-0.682	-0.276**	0.106	-0.340
	(0.132)	(0.096)	(0.578)	(0.139)	(0.096)	(0.538)
$p_{mob_{it}}$	0.206**	-0.156*	0.546	0.303**	-0.343***	0.720
	(0.100)	(0.084)	(0.524)	(0.121)	(0.091)	(0.449)
$p_{mob_{it-1}}$	0.201**	-0.015	0.424	0.161**	0.032	0.268
	(0.084)	(0.068)	(0.333)	(0.064)	(0.077)	(0.323)
$p_{voip_{it}}$	-0.017	-0.043***	-0.170**	-0.226	-0.356	0.375
	(0.025)	(0.015)	(0.082)	(0.414)	(0.318)	(0.871)
$p_{voip_{it-1}}$	-0.028	0.018	0.192	-0.039	0.011	0.105
	(0.025)	(0.020)	(0.190)	(0.030)	(0.029)	(0.154)
$inc_{dsl_{it}}$	0.128**	-0.078	-0.045			
	(0.061)	(0.049)	(0.255)			
$cable/other_{bb_{it}}$	-0.052	0.022	-0.023			
	(0.038)	(0.026)	(0.166)			
$mobile_{bb_{it}}$	0.004	-0.013	0.007			
	(0.010)	(0.015)	(0.071)			
$p_{voip_{it}}\#bb_{lines_{it}}$				-0.018	0.025	-0.334
				(0.030)	(0.023)	(0.064)
$bb_{lines_{it}}$				0.117	-0.155	0.334
				(0.206)	(0.155)	(0.438)
$inc_{mob_{it}}$	0.163*	0.119**	0.625*	0.250***	0.069	0.685**
	(0.090)	(0.058)	(0.360)	(0.097)	(0.090)	(0.319)
$gdp_{pc_{it}}$	0.013	0.130***	-0.210	-0.027	0.191***	-0.309
	(0.047)	(0.028)	(0.187)	(0.025)	(0.036)	(0.199)
$pop_{dens_{it}}$	-0.001*	0.001	-0.010	0.000	0.001	-0.006***
	(0.002)	(0.003)	(0.009)	(0.002)	(0.004)	(0.008)
N	120	120	120	120	120	120
Sargan Test (χ^2)	19.05	17.33	11.16	16.23	19.31	14.06
p-value	0.33	0.43	0.85	0.70	0.50	0.83
AR(4), Prob> z	0.11	0.17	0.56	0.31	0.03	0.52

Significance levels *: 10% **: 5% ***: 1%. Heteroscedasticity robust standard errors in parentheses.
We instrument the lagged dependent and all price variables with their corresponding lags and cost shifters. Sargan test: H0: Overidentifying restrictions are valid. AR test: H0: No autocorrelation.

Chapter 3

The Impact of Tariff Diversity on Broadband Penetration – An Empirical Analysis

Co–authored by Justus Haucap and Ulrich Heimeshoff

3.1 Introduction

Around the globe, policy makers see broadband penetration as a key driver for economic prosperity (OECD, 2008). Ever since the by now seminal study of Röller and Waverman (2001), many other studies provided evidence that broadband has positive effects on growth by directly or indirectly spurring innovation, productivity, and, thereby, a country's national competitiveness.[1] Consequently, a timely deployment and adoption has become a major policy objective for many governments (ITU and UNESCO, 2013).

Given the differences in telecommunications infrastructure, the variety in access technologies and penetration rates across countries, there has been considerable interest in understanding the key factors that drive broadband diffusion. A growing body of empirical literature has analyzed what affects broadband uptake either at a single-country level (Aron and Burnstein, 2003; Denni and Gruber, 2007) or at a cross-country level (e.g., Gruber and Koutroumpis, 2013; Galperin and Ruzzier, 2013; Lin and Wu, 2013; Kongaut and Bohlin, 2014). A large majority of these studies stresses the importance of low prices at an aggregate level in order to promote broadband demand (Lee et al., 2011; Galperin and Ruzzier, 2013; Lin and Wu, 2013). Besides emphasizing the importance of a low price level the International Telecommunication Union (ITU) stated already in 2003 that innovative pricing schemes are needed to attract a wide variety of customers (ITU, 2003, p. 20). However, price dispersion within a country has been neglected entirely in the empirical literature. To the best of our knowledge, our analysis is the first to account for the degree of tariff diversity within a country. This focus is new and hence the main novelty of our paper.

Whilst it is rather clear that the price *level* impacts on broadband uptake, it is from a theoretical perspective less clear how the price *variety*, i.e., tariff diversity,

[1] Koutroumpis (2009) and Czernich et al. (2011), for example, have found a positive impact of broadband penetration on countries' GDP for OECD member states. For non-OECD members, Sassi and Goaied (2013) recently confirm a similar effect for the MENA countries and Chavula (2013) for African countries. Other studies that demonstrate how broadband penetration positively affects economic growth include Jung et al. (2013), Lee et al. (2012), Gruber and Koutroumpis (2011), Thompson and Garbacz (2011), and Lam and Shiu (2010).

should affect broadband penetration. On the one hand, classical industrial economics theory suggests that price discrimination in final consumer markets should lead to an expansion of output (that is increased broadband penetration in the case at hand), as it allows suppliers to serve low-value customers without lowering the price for high-value customers. On the other hand, accounting for recent theories of boundedly rational consumer behavior the prediction becomes less clear. In fact, there has been a burgeoning literature which demonstrates that consumer decisions are prone to mistakes in telecommunications markets (see, e.g., Bolle and Heimel, 2005; Lambrecht and Skiera, 2006; Haucap and Heimeshoff, 2011). Based on these findings, Eliaz and Spiegler (2006), Brown et al. (2010), Piccione and Spiegler (2012), and Herweg and Mierendorff (2013) have developed models which suggest that firms may sometimes deliberately choose to obfuscate consumers in order to increase their profits. Consequently, as Spiegler (2006) has argued, consumers may become confused over "too much variety" or "too many tariffs" and finally reluctant to sign a contract. Actually, the success of flat-rate tariffs in telecommunications markets, associated with a rather modest price variety between offerings, may suggest that simple tariffs might be more helpful in fostering penetration than more diverse and complicated offerings. From a theoretical perspective it is, therefore, not clear how tariff diversity affects broadband uptake: While classical industrial economic theory would suggest a positive relationship between tariff diversity (as a measure for price discrimination) and broadband uptake, the more recently advanced behavioral economics view may suggest a negative one (seeing tariff diversity as a measure for customer obfuscation strategies).

At the same time, many consumer advocates and public interest groups have reacted with skepticism against tendencies to move away from flat rates and introduce greater tariff diversity (see, e.g., Xavier, 2008; Xavier and Ypsilanti, 2010; Rebaï and Flacher, 2013; Lyons, 2013, p. 4). Moreover, universal service obligations sometimes even outrightly prohibit price discrimination. For example, the International Telecommunication Union states that "in many instances, in addition to the requirement for affordable prices, regulators have imposed the requirement of uniform pricing on the operator with the obligation to provide universal service.

Under the uniform pricing policy, the operator is not allowed to differentiate its prices geographically and/or *between consumer types*."[2] Hence, it is useful to empirically analyze how price variety affects penetration rates. While it is true that many developed countries have saturated broadband markets, this is not the case for less developed countries. Furthermore, there is no reason to assume that consumer behavior would follow completely different patterns with respect to NGN penetration or networks with even higher bandwidth in the future.

The purpose of this paper is to provide an empirical assessment for how tariff diversity influences fixed broadband demand, while accounting for other factors that affect broadband penetration.[3] Ensuring reliability of our empirical results, tariff diversity is calculated in various ways based on a newly available data set that originally encompasses more than 1000 broadband-only-offers for 82 countries.[4] Thus, the second major novelty of this paper is, apart from its research focus on tariff diversity, the use of an entirely new data set.

The empirical analysis reveals that increased income and enhanced offerings, such as lower prices and improved quality of service, foster broadband uptake. Besides, an increase in tariff diversity provides a further impetus to broadband adoption, supporting the classical perspective that price discrimination induces output expansion. This finding is of crucial importance because it underlines the necessity for diverse and innovative pricing schemes in order to bridge the digital divide.

The remainder of the paper is organized as follows: In Section 3.2 we summarize the relevant literature. Section 3.3 outlines the empirical strategy and provides a description of our data set. Results are discussed in Section 3.4 and Section 3.5 concludes.

[2]Emphasis added; http://www.itu-coe.ofca.gov.hk/vtm/universal/faq/q1.htm.

[3]Under fixed broadband internet various DSL, cable, fibre, satellite, broadband over power lines and other fixed broadband technologies are subsumed.

[4]All countries included in this study are listed in Table A3.1 in the Appendix.

3.2 Literature review

There is a steadily growing body of literature on the drivers of broadband penetration as an aggregate measure (e.g., Distaso et al., 2006; Lee et al., 2011; Gulati and Yates, 2012; Galperin and Ruzzier, 2013; Lin and Wu, 2013; Kongaut and Bohlin, 2014) and on the determinants of a subcategory of fibre-based broadband (see Briglauer, 2014). These studies have examined various rather invariable endowment factors, e.g., economic prosperity, demographics, and geography as well as influenceable regulatory factors, which may plausibly explain cross-country differences. Given that conventional and fibre-based broadband mainly differ with respect to down- and upload speeds from the demand side's point of view, the obtained results seem to be applicable for both quantifications of internet access technologies. A literature overview is provided in Table A3.2 in the Appendix.

Price: Several studies have accentuated the importance of a low(er) price level in determining broadband demand. Among these studies are Bouckaert et al. (2010), Lee et al. (2011), Galperin and Ruzzier (2013), Lin and Wu (2013), and Briglauer (2014) to name just a few. Lin and Wu (2013), for example, have shown in their diffusion model of broadband adoption in the OECD from 1997 to 2009 that broadband price levels influence the subscription decision, notably for late adopters. Closely related to the present study, Galperin and Ruzzier (2013) estimate the demand elasticity for fixed broadband in Latin America and the Caribbean (LAC) benchmarked against OECD countries in 2010. They provide evidence that demand is quite elastic in countries with a low level of penetration, while in OECD countries demand may actually be inelastic.

Income: Nearly all of the studies referred to above incorporate income levels in their analysis and, somewhat unsurprisingly, identify income as a stimulus for broadband adoption. This finding is confirmed across OECD and non-OECD countries, analyzing either cross-sectional (Garcia-Murillo, 2005; Gulati and Yates, 2012) or time-series data (Cava-Ferreruela and Alabau-Muñoz, 2006; Lee et al., 2011; Gruber and Koutroumpis, 2013; Kongaut and Bohlin, 2014). Gruber and Koutroumpis (2013) clearly detect a positive and significant impact of income on broadband demand in their analysis of 167 countries from 2000 to 2010. In their detailed study of the broadband diffusion process, Lin and Wu (2013) show that disposable household income is of particular importance in the early adoption phase.

Competition: Broadband competition can basically take two forms: (i) facility-based competition between different technological platforms that can be used to provide broadband access, referred to as inter-platform or infrastructure competition, and (ii) service-based competition over the same infrastructure through open access provisions at various network layers, referred to as intra-platform competition.

Numerous studies have found that especially the former has positive effects on broadband penetration (see Höffler, 2007; Lee and Brown, 2008; Bouckaert et al., 2010; Kongaut and Bohlin, 2014). In one of the few single-country studies, Denni and Gruber (2007) use panel data from the US spanning the 1999-2005 period and document that the level of facility-based competition is a potent driver of fixed broadband demand. In a cross-country framework Distaso et al. (2006), using data on 13 EU countries from 2000 to 2004, and Bouckaert et al. (2010), scrutinizing 20 OECD countries for the years 2003-2008, derive similar conclusions. When analyzing technologically advanced and technologically developing countries separately, Gulati and Yates (2012) detect a strong positive impact for developing countries but no effect for advanced countries. Gruber and Koutroumpis (2013), in contrast, provide no evidence for inter-platform competition accelerating conventional broadband demand at all. They deduce that facility-based competition is an impediment to broadband diffusion caused by the duplication of infrastructure. For fibre-based broadband, Briglauer (2014) recently finds an inverted U-shaped relationship between facility-based competition and fibre connections.

With respect to intra-platform competition, the empirical results are ambiguous. Garcia-Murillo (2005), Lee et al. (2011), and lately Gruber and Koutroumpis (2013) show that service-based competition in general and on the incumbent's DSL platform in particular foster broadband uptake. Kongaut and Bohlin (2014) suggest that in the OECD intra-platform competition increases broadband adoption if countries had difficulties implementing inter-platform competition. Using panel data on 16 EU countries for the 1997-2013 period, Klein and Wendel (2014) identify a non-linear relationship between unbundling and penetration. The impact is positive when an intermediate level of broadband penetration has been achieved. However, it is negative if the initial level of broadband penetration is rather low or high. In contrast to the results above, Distaso et al. (2006), Cava-Ferreruela and Alabau-Muñoz (2006), Denni and Gruber (2007), Höffler (2007), and Bouckaert et al. (2010) find only small or insignificant effects of intra-platform competition. Bouckaert et al. (2010) consider two types of intra-platform competition: (a) facility-based intra-platform competition, forcing entrants to invest into their own equipment and facilities when leasing unbundled local loop elements; and (b) service-based intra-platform competition, indicating a lower level of entrants' investments since they only resell the incumbent's services. The authors conclude that neither form of intra-platform competition increases broadband penetration.

In addition to these determinants a number of **other variables** has been examined in the literature. For Trkman et al. (2008), Lee and Brown (2008), Gulati and Yates (2012), and Lin and Wu (2013) demand side characteristics play an important role. They suggest that education positively affects the evolution of broadband, predominantly for the early adopters. Garcia-Murillo (2005), Lee and Brown (2008), and Lin and Wu (2013) further stress that information and communication technology (ICT) use is a main driving force and Cava-Ferreruela and Alabau-Muñoz (2006) suggest that the "predisposition" to use new technologies appears to be essential. Likewise, the presence of domestic content and the available download speed seem to be relevant (Lee and Brown, 2008; Bouckaert et al., 2010). The existence and effectiveness of public institutions and government regulation for the adoption of broadband is emphasized by Gulati and Yates (2012) for broadband adoption as an aggregated measure and by Briglauer (2014) for fibre-based broadband.

All of these studies have contributed to a deeper understanding of broadband adoption. However, none has accounted for the impact of different pricing schemes, presumably due to lack of reasonable tariff information. We contribute to the existing literature by adding tariff diversity as another potential factor to explain differences in broadband penetration across countries when incorporating also the factors identified by the empirical literature.

3.3 Empirical specification and data

3.3.1 Empirical strategy

Several studies demonstrate that consumers' subscription decisions are driven by the current price level as well as a number of demand shifters, including economic prosperity and market structure (e.g., Höffler, 2007; Lee et al., 2011; Galperin and Ruzzier, 2013). To estimate the effect of tariff diversity on fixed broadband demand we specify the demand function for each country as

$$pen_{fix} = f(p_{fix}, diversity, \mathbf{X}) + \epsilon,$$

where pen_{fix} denotes broadband penetration, p_{fix} is the fixed broadband price, *diversity* accounts for price dispersion and ϵ represents an unobservable error term. The vector $\mathbf{X}$ includes download speed, income per capita, the level of education, and the degrees of facility-based and service-based competition. The fixed broadband demand model which we estimate is thus given by

$$\begin{aligned} pen_{fix} = \beta_0 + \beta_1 p_{fix} + \beta_2 diversity + \beta_3 speed + \beta_4 income_{pc} \\ + \beta_5 educ + \beta_6 comp_{facility} + \beta_7 comp_{service} + \epsilon. \end{aligned}$$

According to economic theory of a downward sloping demand curve for ordinary goods and services, a negative impact of price on broadband diffusion is predicted. The impact of tariff diversity is not clear ex ante. An increased variety in pricing schemes may either trigger consumers to buy, by that supporting the classical industrial economic theory, or make consumers refrain from buying, backing the more recently developed behavioral economics view of a negative relationship between price dispersion and demand. To characterize at least two main dimensions of fixed-line broadband offerings, we include price-related variables and the advertised download speed. A higher download speed, that is a higher quality of service, is predicted to positively affect consumers' willingness to pay, thereby increasing demand for broadband services for a given price level.[5] We control for the effects of economic prosperity on demand by including the average income per inhabitant. Education is included because (digital) literacy is found to reduce the inability to use digital technologies and to increase the demand for more sophisticated ICT services (Gulati and Yates, 2012; Galperin and Ruzzier, 2013). Controlling for the level of education further indirectly captures that with improved linguistic skills more content becomes accessible. Facility-based competition, i.e., rivalry between technologies, is conjectured to be one determinant in promoting broadband adoption by expanding potential broadband coverage and reducing prices, although it might come at the cost of (partly) duplicating existing network infrastructure (Höffler, 2007; Bouckaert et al., 2010; Gruber and Koutroumpis, 2013). Our expectations for intra-platform competition are mixed. On the one hand, service-based competition is expected to foster diffusion since substitutability, due to a comparable geographical coverage and quality of service, may reduce prices as competitive pressure becomes fiercer. On the other hand, Klein and Wendel's and Kongaut and Bohlin's recent findings point to a negative or insignificant effect, at least for countries with a lower level of broadband penetration.

We apply an instrumental variable approach since both price-related variables as well as the income variable are potentially endogenous. Endogeneity of the price-related variables may arise because the price level and the penetration rate are determined simultaneously in equilibrium. Moreover, measures for tariff diversity might be correlated with unobserved market structure variables. For the price variable optimal instruments are supply shifters that influence the costs of providing telecommunications services but are not correlated with the error term of the regression. Firstly, assuming that in the presence of economies of scale operators set lower prices when they serve more subscribers, we use the previous internet subscription as an instrument. Given a restricted contract period of at most two years, we suppose that the number of fixed broadband subscribers in year t is indepen-

[5] Other tariff characteristics which may further differentiate the service, and by that impacting on consumers' willingness to buy, are not observable or quantifiable. Unobservable characteristics are, for example, the network stability, service offers or special promotions by providers.

dent of the number of fixed internet subscribers in $t-2$. Secondly, we account for different costs of infrastructure deployment and maintenance by including the level of urbanization. If providers are unable to exploit economies of scale and scope in countries with a low level of urbanization, this should hinder price reductions of broadband services. In addition to these cost shifters, we include two indicators for political and economic freedom.[6] These variables measure the degree of insecurity and uncertainty in economic relationships. Since investments are largely irreversible in a network-based industry, the political and legal environment is crucial for the supply side.

We instrument the price dispersion variables by using the average price differentiation in all neighboring countries as well as the respective measure of the most closely related neighboring market. This instrumentation strategy is reasonable if we assume that geographical and thus cost conditions are comparable across neighboring countries but demand shocks occur at the country level. We refer to these instruments as Hausman instruments (see Hausman, 1996).

A second source of endogeneity may result from reversed causality. A growing income possibly leads to higher investments into infrastructure and increased usage of technologies, eventually resulting in higher future income. The positive effect of telecommunications infrastructure and broadband infrastructure in particular is well established in the literature as the papers by Röller and Waverman (2001) and Czernich et al. (2011) show. As a consequence, broadband adoption and income may be determined simultaneously. Following Gruber and Koutroumpis (2013), we use the one-year lag of income, as broadband adoption affects future, but not past income.

3.3.2 Data

Our main data sources are the ITU World Telecommunications Indicators Database, Google, the World Bank, the Human Development Report, and the Heritage Foundation. Data on fixed broadband penetration rates, prices, subscription levels for

[6] See Duso and Röller (2003) for an example of the application of political variables as instruments.

the different fixed broadband technologies, the number of fixed internet subscribers as well as the average advertised download speed are provided by ITU. Tariff diversity and the number of DSL operators in a country are based on the data gathered by Google (2012).[7] Income per capita and the urban population are retrieved from World Bank. Education is taken from the Human Development Report and the indicators for political and economic freedom are obtained from the Heritage Foundation. Data is from 2012 and comprises 82 OECD and non-OECD countries. Table A3.3 provides a detailed description of all the regression variables.

Variables are defined as follows. As in most studies, the fixed-line broadband penetration levels are measured in 100 of population (cf. Cava-Ferreruela and Alabau-Muñoz, 2006; Lee et al., 2011; Gulati and Yates, 2012; Lin and Wu, 2013).[8] Broadband penetration is considered to be any dedicated connection to the internet at downstream speeds equal to, or greater than, 256 Kbps. The fixed broadband price refers to the monthly subscription charge for fixed broadband internet service. With several offers available, preference is given to the 256 Kbps connection which is usually one of the cheapest tariffs. Thus, the price variable is assumed to be a lower boundary for the average price in a country. A country's tariff diversity is calculated as three measures of central tendency for the reported prices: the standard deviation (sd), the difference between minimum and mean (mm) and the average absolute deviation from the median (adm). Download speed refers to the average advertised maximum theoretical download speed in Mbps, not to speeds guaranteed to users associated with a monthly subscription. The educational level is approximated by the expected years of schooling and the average income per inhabitant by the GNI per capita. Facility-based competition is measured by the Herfindahl-Hirschman Index (HHI) of DSL, cable, and all other fixed broadband technologies (including fibre, satellite, broadband over power lines, and WiMax). The HHI is defined as the sum of technologies' squared market shares. A higher HHI is equivalent to a more asymmetric market structure, implying less competition between the technologies.

[7]The pricing data by Google was spot-checked at the end of 2012 by visiting operators' websites. No significant deviations were detected, hence the data is perceived to be reliable.

[8]When using household penetration, the number of subscribers per 100 households, as in Höffler (2007) or in Galperin and Ruzzier (2013), our results do not change significantly.

The measure for service-based competition is calculated as the number of active operators in the DSL market as provided by Google. Acknowledging that the Google data set has no claim to be comprehensive, the number of active DSL providers is a lower boundary. The number of fixed internet subscribers in 2010 includes both active fixed internet subscriptions at speeds lower than 256 Kbps (narrowband) and greater than 256 Kbps (broadband). To account for varying political and social conditions the Index of Freedom from Corruption and the overall score of the Index of Economic Freedom are included. These indicators rate a country on a scale from 0 to 100; a higher score indicates a stronger rule of law.

All variables are expressed in logarithms in order to interpret them as elasticities and all price-related variables are measured in US dollars. Summary statistics and the correlation matrix between the regression variables are presented in Tables A3.4 and A3.5 in the Appendix, respectively.

3.4 Empirical Results

3.4.1 Main results

Estimation results from our baseline specification are presented in Table 3.1. We report the results obtained from the OLS regressions in columns (1)-(3) and those estimated with the two-stage least-squares (2SLS) approach in columns (4)-(6). To test for the exogeneity of the employed instruments, we apply the Sargan/Hansen's J test. The obtained test statistics indicate that the null hypothesis of valid over-identifying restrictions cannot be rejected. The Hausman test rejects the null hypothesis of exogeneity in each specification at least at the 10% level. The first-stage F statistics of excluded instruments approximate to 10, confirming the relevance of the utilized instruments. Hence, the tests confirm that our instruments are relevant, that is have a high correlation with the endogenous explanatory variables, and are exogenous, i.e., uncorrelated with the error term. In each 2SLS specification all variables have the expected signs. We identify a robust statistically significant effect of the price variable, tariff diversity, income, the advertised download speed, and education.

For brevity, we solely discuss the consistent coefficients of the 2SLS regressions in more detail. In specification (4) the price elasticity is negative (-1.91) and significant at the 1%-level. An elasticity of this magnitude denotes, ceteris paribus, that a price decrease of 1% rises demand for broadband by 1.91%. Given this elastic own-price elasticity, price reductions could significantly increase adoption. Tariff diversity, abbreviated as $diversity_{sd}$, is measured as the standard deviation of prices. The impact of tariff diversity is positive (+0.52) and significant, meaning that a 1% increase in the standard deviation increases demand by 0.52%. This result is in line with the classical economic view that price discrimination in final consumer markets entails an expansion of output and demand. A positive relationship is indicative of the importance of innovative pricing schemes in expediting the ascent of broadband internet access as pointed out by ITU (2003).[9] Besides, the positive and significant coefficient of the advertised download speed, implies that a higher quality of service increases the willingness to buy broadband internet access, probably because higher bandwidths allow the use of more sophisticated applications. The socio-economic variables, income and education, have a strong positive and significant impact on broadband demand. Higher income enables consumers to spend more on telecommunication services, while a higher level of education reduces barriers to broadband adoption. Additionally, with a higher level of education the utility of internet usage might increase, for instance, as more content (in foreign languages, e.g., in English) becomes utilizable. The two competition variables have the expected signs. However, we do not find any statistically significant effect. This is in line with the findings of Gruber and Koutroumpis (2013) for facility-based competition and, for instance, Distaso et al. (2006), Denni and Gruber (2007), and Bouckaert et al. (2010) for service-based competition. A possible explanation might be that a positive effect of competition in some countries (with an already established infrastructure and intermediate penetration level) is counterbalanced by a negative relationship in other countries with low current infrastructure stock (cf. Klein and Wendel, 2014).

[9] Accounting for non-linearity in price dispersion turned out to be insignificant.

Table 3.1: Estimation results

Dependent variable: pen_{fix}

	OLS			2SLS		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Tariff characteristics						
p_{fix}	-0.35	-0.24	-0.30	-1.91***	-1.96***	-1.90***
	(0.22)	(0.22)	(0.18)	(0.44)	(0.44)	(0.43)
$diversity_{sd}$	0.03			0.52*		
	(0.14)			(0.29)		
$diversity_{mm}$		0.01			0.58*	
		(0.15)			(0.35)	
$diversity_{adm}$			-0.05			0.56*
			(0.14)			(0.29)
speed	0.19**	0.17*	0.42***	0.39**	0.38**	0.40**
	(0.09)	(0.09)	(0.11)	(0.16)	(0.15)	(0.16)
Demographics						
$income_{pc}$	0.61*	0.57	0.50*	0.92***	0.95***	0.93***
	(0.36)	(0.34)	(0.26)	(0.36)	(0.34)	(0.34)
educ	3.27**	3.20***	2.62***	2.79*	2.58***	2.79*
	(1.31)	(1.21)	(0.79)	(1.51)	(1.47)	(1.54)
Market structure						
$comp_{facility}$	-0.45	-0.57	-0.12	-0.04	-0.08	-0.04
	(0.38)	(0.37)	(0.33)	(0.49)	(0.50)	(0.48)
$comp_{service}$	-0.01	0.06	-0.08	0.08	0.03	0.07
	(0.22)	(0.20)	(0.20)	(0.32)	(0.32)	(0.32)
Intercept	-11.77***	-11.48***	-9.49***	-9.97***	-9.71***	-9.99***
	(1.58)	(1.36)	(1.33)	(2.56)	(2.69)	(2.69)
No. of observations	71	71	71	71	71	71
Sargan/Hansen[a]				0.19	0.16	0.18
Underidentification[a]				0.01	0.02	0.06
F of excl. IVs: p_{fix}				10.32	9.92	9.77
F of excl. IVs: $diversity_j$				16.19	23.62	17.26
Hausman[a]				0.09	0.01	0.01

Significance levels: $*$: 10% $**$: 5% $***$: 1%.
Heteroscedasticity robust standard errors in parentheses.
[a] p-values are reported.

In specifications (5) and (6) tariff diversity at the country level is either calculated as the range between the minimum and the mean, $diversity_{mm}$, or the average absolute deviation from the median, $diversity_{adm}$, of the broadband plans' prices. Both regressions basically show the same results as before. The own-price elasticities are highly significant, negative and in the elastic range (-1.96 and -1.90). The coefficients of $diversity_{mm}$ and $diversity_{adm}$ are significant and positively related to broadband demand (+0.52 and +0.56), the same holds for the third tariff characteristic *speed* (+0.38 and +0.40). Advancements in the financial and educational background are found to intensify broadband adoption. Again we detect no effect of the degrees of facility-based and service-based competition on demand.

Overall, our results provide strong evidence of significant price-related effects. As intended by numerous governments, price reductions are the main key factors to spur broadband adoption. The estimated own-price elasticities exceed previous estimates (Bouckaert et al., 2010; Lee et al., 2011; Galperin and Ruzzier, 2013), likely due to the quite recent data which underlies our analysis. In addition, our analysis reveals that price diversity positively affects demand. Consequently, pricing schemes have to be diversified in order to attract different classes of consumers. As confirmed by other studies, we find that quality of service, income, and the level of education are important determinants of demand for broadband services.

3.4.2 Robustness checks

We assess the robustness of our results by employing additional specifications. To account for standardized systems of law and regulatory frameworks, we include regional effects for Africa, Asia-Pacific, Europe, and LAC as well as a binary variable indicating OECD membership. Further, as common in other studies, we replace the continuous competition measures with dummy variables (e.g., Cava-Ferreruela and Alabau-Muñoz, 2006; Garcia-Murillo, 2005; Kongaut and Bohlin, 2014).[10] The inter-platform competition variable equals one if there is at least one DSL and one

[10] As a further robustness check, we also calculated the HHI as the sum of technologies' squared market shares of (i) DSL and non-DSL technologies and (ii) for DSL, cable, fibre, and all other technologies. However, results do not change.

Table 3.2: Robustness checks

Dependent variable: pen_{fix}

Variable	2SLS full sample (1)	(2)	(3)	2SLS $\leq$ 20% (4)	(5)	(6)
Tariff characteristics						
p_{fix}	-2.54***	-1.81***	-1.97***	-3.11***	-2.38***	-2.23***
	(0.66)	(0.40)	(0.46)	(0.86)	(0.53)	(0.50)
$diversity_{sd}$	0.67*			0.89*		
	(0.38)			(0.47)		
$diversity_{mm}$		0.56*			0.66*	
		(0.32)			(0.39)	
$diversity_{adm}$			0.46*			0.46*
			(0.25)			(0.26)
speed	0.47**	0.29**	0.28*	0.29	0.15	0.17
	(0.20)	(0.13)	(0.16)	(0.24)	(0.22)	(0.21)
Demographics						
$income_{pc}$	1.33***	0.91***	0.87***	1.38***	0.99***	0.90***
	(0.27)	(0.32)	(0.30)	(0.28)	(0.31)	(0.32)
educ		2.08	2.12*		1.62	1.70
		(1.37)	(1.29)		(1.40)	(1.43)
Market structure						
$comp_{facility}$			0.03			-0.01
			(0.45)			(0.57)
$comp_{service}$		0.06	0.03		-0.31	-0.21
		(0.29)	(0.32)		(0.41)	(0.40)
$dummy_{facility}$	0.50	0.19		0.67	0.32	
	(0.46)	(0.35)		(0.56)	(0.47)	
$dummy_{service}$	0.33			-0.20		
	(0.35)			(0.51)		
Intercept	-5.52*	-8.82***	-7.35***	-5.02	-7.04**	-6.06*
	(3.20)	(2.51)	(2.86)	(3.55)	(3.42)	(3.32)
Regional effects	No	Yes	Yes	No	Yes	Yes
No. of observations	82	71	71	61	53	53
Sargan/Hansen[a]	0.38	0.17	0.23	0.49	0.48	0.36
Underidentification[a]	0.01	0.01	0.02	0.08	0.06	0.09
F of excl. IVs: p_{fix}	11.86	10.24	11.94	9.22	9.47	9.55
F of excl. IVs: $diversity_j$	22.91	20.03	16.39	21.90	18.78	16.62
Hausman[a]	0.06	0.03	0.01	0.1	0.08	0.01

Significance levels: $*$: 10% $**$: 5% $***$: 1%.
Heteroscedasticity robust standard errors in parentheses.
[a] p-values are reported.

non-DSL operator and the intra-platform competition dummy equals one if at least two DSL operators are active in a country.

We estimate the robustness checks for the full sample and a reduced sample comprising only countries with a penetration rate equal or less than 20%. The sample reduction permits to evaluate the effects of different demand shifters for (technologically) developing countries separately. This is of crucial importance because their shortages should first be addressed in order to bridge the digital divide. Table 3.2 states the robustness checks for the full sample in columns (1)-(3) and for the sub-sample in columns (4)-(6).

When including regional effects and/or competition dummies, our results continue to hold for all calculation methodologies of tariff diversity. Regarding the full sample regressions, a robust positive relationship is recorded between broadband penetration and reduced prices, broadened tariff diversity, enhanced download speed, increased income, and a higher level of education.

Considering the sub-sample of 63 almost exclusively non-OECD countries, our principle results remain valid across all specifications. As for the full sample, there is convincing evidence that demand is boosted by a reduction of prices, increased tariff diversity, and available income. In line with Lin and Wu (2013) and Galperin and Ruzzier (2013), we find that the own-price effect is amplified in comparison to the full sample, underpinning the importance of affordable prices for late adopters. The consistent and partly even increased positive effect of tariff diversity highlights the benefits of innovative pricing schemes.

3.5 Conclusion

The present paper is the first to analyze the effect of tariff diversity on the adoption of broadband internet access using a cross-country sample of 82 OECD and non-OECD member states. The majority of cross-national studies has considered OECD countries only but their results have been generalized to apply to all countries alike. Only a few studies deal with non-OECD member states explicitly as we do. In contrast to previous studies (e.g., Gulati and Yates, 2012), we are able to analyze the effect of various factors on diffusion also in the least developed countries, which is of crucial importance given that developing countries are still lagging behind in the digitalization of various fields of society.

Avoiding possible endogeneity problems regarding our estimation strategy, we apply an instrumental variable approach. To measure tariff diversity at the country-level, a detailed data set comprising over 1000 fixed-line broadband tariffs is used. We find evidence that primarily price-related and socio-economic factors determine broadband penetration. Especially the broadband price level crucially matters: Low prices are the key driver to foster adoption, particularly for countries with a low level of broadband penetration. A higher income, a better education as well as an improved quality of service are further stimuli to broadband adoption. In addition, tariff diversity significantly enhances demand. As suggested by traditional economic theory, price discrimination seems to enlarge output and demand by serving also consumers with a low willingness to pay. This result suggests that policy makers should be lenient towards price discrimination in broadband markets. Demands by some public interest groups to limit price discrimination in broadband markets (see, e.g., Lyons, 2013) should be viewed with some caution according to our findings, as reduced price discrimination may come at the cost of lower penetration rates.

There are some limitations of this study which should be kept in mind. Our findings seem to be applicable for developing and developed markets. However, given that the majority of countries included in the analysis are non-OECD members, the obtained results may especially apply to emerging markets. Furthermore, aggregated data at the country level is used which makes it impossible to account for differences within a country. This is an aspect that has also been pointed out by other authors in the literature (Kim et al., 2003; Garcia-Murillo, 2005). Finally, broadband adoption, like any process of technology diffusion, is seen as a dynamic development. Such a process of adoption evolves through time and this feature cannot be taken into account in a cross-sectional estimation model. Consequently, future research may use panel data once the necessary time series become available for a sufficient number of countries. For now, it is beyond the scope of our paper to measure adoption of broadband services over time. We are concerned with the effects of tariff diversity on broadband adoption in the cross section. Compared to panel data, it is more difficult to avoid biases due to unobserved heterogeneity and missing variables. As a result, we interpret our results with some caution. On the other hand, we apply instrumental variable approaches for variables where we feel the need to avoid biases due to potential endogeneity. Due to careful analysis using instrumental variables and several robustness checks, we are able to show that our results are reasonably robust. Creating a panel to analyze the effects of tariff diversity over time and getting a better picture of the relationship between tariff diversity and the process of broadband adoption is a topic of its own which we have to leave for future research.

In conclusion, the results obtained by the model provide some useful first insights and point to the importance of factors that are often overlooked in broadband policy, namely the design of pricing schemes. Further research on the role tariff diversity, using time-series data, appears highly desirable.

Bibliography

Aron, D. J. and Burnstein, D. E. (2003). Broadband adoption in the United States: An empirical analysis. In Shampine, A. L., editor, *Down to the Wire: Studies in the Diffusion and Regulation of Telecommunications Technologies*.

Bolle, F. and Heimel, J. (2005). A fallacy of dominant price vectors in network industries. *Review of Network Economics*, 4(3):1–8.

Bouckaert, J., van Dijk, T., and Verboven, F. (2010). Access regulation, competition, and broadband penetration: An international study. *Telecommunications Policy*, 34(11):661–671.

Briglauer, W. (2014). The impact of regulation and competition on the adoption of fiber-based broadband services: Recent evidence from the European Union member states. *Journal of Regulatory Economics*, 46(1):51–79.

Brown, J., Hossain, T., and Morgan, J. (2010). Shrouded attributes and information suppression: Evidence from the field. *The Quarterly Journal of Economics*, 125(2):859–876.

Cava-Ferreruela, I. and Alabau-Muñoz, A. (2006). Broadband policy assessment: A cross-national empirical analysis. *Telecommunications Policy*, 30(8-9):445–463.

Chavula, H. (2013). Telecommunications development and economic growth in Africa. *Information Technology for Development*, 19(1):5–23.

Czernich, N., Falck, O., Kretschmer, T., and Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal*, 121(552):505–532.

Denni, M. and Gruber, H. (2007). The diffusion of broadband telecommunications in the U.S. – The role of different forms of competition. *Communications & Strategies*, 68:139–157.

Distaso, W., Lupi, P., and Manenti, F. M. (2006). Platform competition and broadband uptake: Theory and empirical evidence from the European Union. *Information Economics and Policy*, 18(1):87–106.

Duso, T. and Röller, L.-H. (2003). Endogenous deregulation: Evidence from OECD countries. *Economics Letters*, 81(1):67–71.

Eliaz, K. and Spiegler, R. (2006). Contracting with diversely naive agents. *The Review of Economic Studies*, 73(3):689–714.

Galperin, H. and Ruzzier, C. A. (2013). Price elasticity of demand for broadband: Evidence from Latin America and the Caribbean. *Telecommunications Policy*, 37(6-7):429–438.

Garcia-Murillo, M. (2005). International broadband deployment: The impact of unbundling. *Communications & Strategies*, 57:83–105.

Google (2012). International broadband pricing study: Dataset for public use.

Gruber, H. and Koutroumpis, P. (2011). Mobile telecommunications and the impact on economic development. *Economic Policy*, 26(67):387–426.

Gruber, H. and Koutroumpis, P. (2013). Competition enhancing regulation and diffusion of innovation: The case of broadband networks. *Journal of Regulatory Economics*, 43(2):168–195.

Gulati, G. J. and Yates, D. J. (2012). Different paths to universal access: The impact of policy and regulation on broadband diffusion in the developed and developing worlds. *Telecommunications Policy*, 36(9):749–761.

Haucap, J. and Heimeshoff, U. (2011). Consumer behavior towards on-net/off-net price differentiation. *Telecommunications Policy*, 35(4):325–332.

Haucap, J., Heimeshoff, U., and Lange, M. R. J. (2016). The impact of tariff diversity on broadband penetration – An empirical analysis. *Telecommunications Policy*, 40(8):743–754.

Hausman, J. A. (1996). *Valuation of New Goods under Perfect and Imperfect Competition*, pages 207–248. University of Chicago Press.

Herweg, F. and Mierendorff, K. (2013). Uncertain demand, consumer loss aversion, and flat-rate tariffs. *Journal of the European Economic Association*, 11(2):399–432.

Höffler, F. (2007). Cost and benefits from infrastructure competition. Estimating welfare effects from broadband access competition. *Telecommunications Policy*, 31(6-7):401–418.

ITU (2003). Promoting broadband: Background paper.

ITU and UNESCO (2013). The state of broadband 2013: Universalizing broadband.

Jung, H.-J., Na, K.-Y., and Yoon, C.-H. (2013). The role of ICT in Korea's economic growth: Productivity changes across industries since the 1990s. *Telecommunications Policy*, 37(4-5):292–310.

Kim, J., Bauer, J. M., and Wildman, S. S. (2003). Broadband uptake in OECD countries: Policy lessons from comparative statistical analysis. SSRN Scholarly Paper, Rochester, NY.

Klein, G. J. and Wendel, J. (2014). The impact of local loop and retail unbundling revisited. DICE Discussion Papers 163, Heinrich-Heine-Universität Düsseldorf.

Kongaut, C. and Bohlin, E. (2014). Unbundling and infrastructure competition for broadband adoption: Implications for NGA regulation. *Telecommunications Policy*, 38(8-9):760–770.

Koutroumpis, P. (2009). The economic impact of broadband on growth: A simultaneous approach. *Telecommunications Policy*, 33(9):471–485.

Lam, P.-L. and Shiu, A. (2010). Economic growth, telecommunications development and productivity growth of the telecommunications sector: Evidence around the world. *Telecommunications Policy*, 34(4):185–199.

Lambrecht, A. and Skiera, B. (2006). Paying too much and being happy about it: Existence, causes and consequences of tariff-choice biases. *Journal of Marketing Research*, 18(2):212–223.

Lee, S. and Brown, J. S. (2008). Examining broadband adoption factors: An empirical analysis between countries. *info*, 10(1):25–39.

Lee, S., Marcu, M., and Lee, S. (2011). An empirical analysis of fixed and mobile broadband diffusion. *Information Economics and Policy*, 23(3-4):227–233.

Lee, S. H., Levendis, J., and Gutierrez, L. (2012). Telecommunications and economic growth: An empirical analysis of sub-Saharan Africa. *Applied Economics*, 44(4):461–469.

Lin, M.-S. and Wu, F.-S. (2013). Identifying the determinants of broadband adoption by diffusion stage in OECD countries. *Telecommunications Policy*, 37(4-5):241–251.

Lyons, D. (2013). Internet policy's next frontier: Usage-based broadband pricing. *Federal Communications Law Journal*, 66(1):1–44.

OECD (2008). Broadband growth and policies in OECD countries.

Piccione, M. and Spiegler, R. (2012). Price competition under limited comparability. *The Quarterly Journal of Economics*, 127(1):97–135.

Rebaï, L. and Flacher, D. (2013). Complexité Tarifaire et Choix de Consommation: Une Application aux Services de Télécommunications en Tunisie. *Revue d'Économie Industrielle*, 143:133–176.

Röller, L.-H. and Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *The American Economic Review*, 91(4):909–923.

Sassi, S. and Goaied, M. (2013). Financial development, ICT diffusion and economic growth: Lessons from MENA region. *Telecommunications Policy*, 37(4-5):252–261.

Spiegler, R. (2006). Competition over agents with boundedly rational expectations. *Theoretical Economics*, 1(2):207–231.

Thompson, H. G. J. and Garbacz, C. (2011). Economic impacts of mobile versus fixed broadband. *Telecommunications Policy*, 35(11):999–1009.

Trkman, P., Blazic, J. B., and Turk, T. (2008). Factors of broadband development and the design of a strategic policy framework. *Telecommunications Policy*, 32(2):101–115.

Xavier, P. (2008). Enhancing Competition in Telecommunications: Protecting and Empowering Consumers. Report commissioned by OECD.

Xavier, P. and Ypsilanti, D. (2010). Behavioral economics and telecommunications policy. In Gentzoglanis, A. and Henten, A., editors, *Regulation and the Evolution of the Global Telecommunications Industry*, chapter 4, pages 83–106. Edward Elgar, Cheltenham.

Appendix

Table A3.1: Countries

Algeria	Denmark	Korea (South)	*Slovak Republic*
Angola	*Dominican Rep.*	*Kyrgyzstan*	Slovenia
Argentina	*Ecuador*	*Lao P.D.R.*	*South Africa*
Australia	*Egypt*	*Malaysia*	Spain
Austria	*El Salvador*	*Mali*	*Sri Lanka*
Azerbaijan	Finland	*Mexico*	Sweden
Bangladesh	France	*Morocco*	Switzerland
Belgium	Germany	*Nepal*	*Syria*
Benin	*Greece*	Netherlands	*Tajikistan*
Bolivia	*Guatemala*	*Nicaragua*	*Tanzania*
Brazil	*Honduras*	*Niger*	*Uganda*
Bulgaria	Hong Kong, China	*Pakistan*	*Ukraine*
Burkina Faso	*Hungary*	*Paraguay*	*United Arab Emirates*
Cambodia	*India*	*Peru*	United Kingdom
Cameroon	*Indonesia*	*Philippines*	United States
Canada	*Iran (Islamic Rep.)*	*Poland*	*Uzbekistan*
Chile	Israel	*Portugal*	*Venezuela*
China	Italy	*Saudi Arabia*	*Yemen*
Colombia	Japan	*Senegal*	*Zambia*
Cote d'Ivoire	*Jordan*	*Serbia*	
Czech Republic	*Kenya*	Singapore	

Countries printed in italic correspond to the tested sub-sample.

Table A3.2: Broadband demand studies

Author	Country & period	Method	Dep. Var.	Key driving factors
Bouckaert et al. (2010)	20 OECD countries; 2003-2008	RE model	Broadband pen.	Inter-platform competition, intra-platform competition (facility- and service-based) have smaller effects, speed, income, population density, PC access and broadband price.
Briglauer (2014)	EU; 2004-2012	static+dynamic FE model	Fibre pen.	Effectiveness of broadband access regulation, competitive pressure from mobile networks, previous fibre penetration.
Cava-Ferreruela and Alabau-Muñoz (2006)	30 OECD countries; 2000-2002	Correlation analysis+POLS	DSL+cable pen.	Income, inter-platform competition, cost of deploying infrastructure and number of dial-up Internet users.
Denni and Gruber (2007)	US; 1999-2005	Diffusion model (RE+FE)	Broadband pen.	Inter-platform competition. The diffusion speed diminishes with the number of firms and the size of the firms.
Distaso et al. (2006)	14 EU countries; 2000-2004	FE-IV regression	Broadband pen.	Inter-platform competition, lower prices of LLU.
Galperin and Ruzzier (2013)	23 LAC + 29 OECD countries; 2010	OLS+2SLS	Broadband pen.	Price level, education, age.
Garcia-Murillo (2005)	100 countries; 2001	Logit regression model+OLS	Broadband pen.	Income, population density, (domestic) content, inter- and intra-platform competition.
Gruber and Koutroumpis (2013)	167 countries; 2000-2010	Diffusion model	Broadband pen.	Intra-platform competition.
Gulati and Yates (2012)	108 countries; 2008	OLS	Broadband pen.	Technologically advanced countries: investment in ICT, governments and regulation, education, urbanization; technologically developing countries: inter-platform competition, investment in ICT, democratic political structures, income, income inequality.
Höffler (2007)	16 Western European countries; 2000-2004	POLS+IV	Broadband pen.	Inter-platform competition from cable TV (inverted U-shape).
Kim et al. (2003)	30 OECD countries; 2001	OLS	Broadband pen.	"Technological preparedness", population density.
Klein and Wendel (2014)	16 EU countries; 1997-2013	OLS+FE	Broadband pen.	Intra-platform competition positive or negative depending on level of broadband penetration.
Kongaut and Bohlin (2014)	30 OECD countries; 2002-2008	2SLS + G2SLS	Broadband pen.	Income, urbanization, PC penetration, inter-platform competition, intra-platform competition if countries had difficulties encouraging inter-platform competition.
Lee and Brown (2008)	110 countries; 2005	OLS	Broadband pen.	Inter-platform competition, broadband speed, ICT use and content.
Lee et al. (2011)	30 OECD countries; 2000-2008	Logistic diffusion model	Broadband pen.	Local loop unbundling, price level, income, education, population density.
Lin and Wu (2013)	34 OECD countries; 1997-2009	Gompertz diffusion model	Broadband pen.	Early adopter: income, education, content; early majority: platform competition, previous broadband penetration; late majority and laggard: broadband price.
Trkman et al. (2008)	25 EU countries; 2006	Factor analysis	Broadband pen.	Communication technology expenditures, PC access, internet penetration, income, fixed phone penetration, population density, education.

Table A3.3: Variables description and source

Variable	Description	Source, Year
pen_{fix}	Fixed broadband penetration [subscriptions per 100 inhabitants].	ITU, 2012
p_{fix}	Fixed broadband monthly subscription charge [in US dollars].	ITU, 2012
speed	Average advertised maximum download speed for fixed broadband connection [in Mbps].	ITU, 2012
$diversity_{sd}$	Standard deviation of prices of fixed broadband offerings in a country.	Google, 2012
$diversity_{mm}$	Difference between minimum and mean of prices of fixed broadband offerings in a country.	Google, 2012
$diversity_{adm}$	Average absolute deviation from the median of prices of fixed broadband offerings in a country.	Google, 2012
$income_{pc}$	GNI per capita [in US dollars].	World Bank, 2011
educ	Expected years of schooling.	Human Development Report, 2011
$comp_{facility}$	Herfindahl-Hirschman Index of DSL, cable and other fixed broadband technologies.	ITU, 2012
$comp_{service}$	Number of competing DSL operators.	Google, 2012
$dummy_{\text{facility}}$	Dummy variable; equal to 1 if there is at least one DSL and one non-DSL operator in a country, zero otherwise.	Google, 2012
$dummy_{\text{service}}$	Dummy variable; equal to 1 if there are at least two DSL operators in a country, zero otherwise.	Google, 2012.
urban	Urban population [in 10,000].	World Bank, 2012
$internet_{2010}$	Fixed internet subscriptions in 2010 [in 10,000].	ITU, 2012
free	Index of Freedom from Corruption [0-100].	The Heritage Foundation, 2012
score	Index of Economic Freedom [0-100].	The Heritage Foundation, 2012
iv_{sd}	Standard deviation of fixed broadband offers in the closest related neighboring country.	Google, 2012
$iv_{sd,av}$	Average Standard deviation of fixed broadband offers in all neighboring countries.	Google, 2012
iv_{mm}	Difference between minimum and mean of fixed broadband offers in the closest related neighboring country	Google, 2012
$iv_{mm,av}$	Average difference between minimum and mean of fixed broadband offers in all neighboring countries.	Google, 2012
iv_{adm}	Average absolute deviation from the median of fixed broadband offers in the closest related neighboring country	Google, 2012
$iv_{adm,av}$	Average of the average absolute deviation from the median of fixed broadband offers in all neighboring countries.	Google, 2012

Table A3.4: Summary statistics

Variable	Measured in	Mean	Std. Dev.	Min.	Max.	N
pen_{fix}	per 100 inhabitants	12.13	12.9	0.02	40.15	82
p_{fix}	US dollars	25.7	14.5	4.2	89.1	82
$diversity_{sd}$	US dollars	32.4	30.7	1.8	118.1	82
$diversity_{mm}$	US dollars	31.5	26.0	1.3	102.5	82
$diversity_{adm}$	US dollars	22.9	21.9	1.3	87.8	82
$speed$	Mbps	4.5	7.8	0.3	50	82
$income_{pc}$	US dollars	14,624.8	14,449.2	10	59,993.2	82
$educ$	years	12.9	3.0	4.9	18	82
$comp_{facility}$	0-10,000	6457	2466	0	10,000	82
$comp_{service}$		1.7	0.9	1	4	71
$dummy_{facility}$		0.7	0.5	0	1	82
$dummy_{service}$		0.4	0.5	0	1	82
$internet_{2010}$	10,000 inhabitants	578.2	1723.4	0.1	12633.7	82
$free$	0-100	42.7	23.5	10	93	82
$score$	0-100	46.8	26.0	5	90	82
$urban$	10,000 inhabitants	3,523.6	8,307.6	99.2	6,0068.3	82
iv_{sd}	US dollars	32.0	27.8	4.6	118.1	82
$iv_{sd,av}$	US dollars	32.3	21.3	4.6	106.1	82
iv_{mm}	US dollars	32.2	26.4	4.0	98.5	82
$iv_{mm,av}$	US dollars	32.2	18.7	9.2	90.7	82
iv_{adm}	US dollars	24.3	17.5	4.9	85.9	82
$iv_{adm,av}$	US dollars	23.5	12.9	6.3	59.0	82

Variables are expressed in levels.

Table A3.5: Cross-correlation table

Variables	pen_{fix}	p_{fix}	$diversity_{sd}$	$diversity_{mm}$	$diversity_{adm}$
pen_{fix}	1.000				
p_{fix}	0.105	1.000			
$diversity_{sd}$	-0.450*	0.009	1.000		
$diversity_{mm}$	-0.396*	0.083	0.950*	1.000	
$diversity_{adm}$	-0.457*	-0.003	0.989*	0.965*	1.000
$speed$	0.670*	0.256*	-0.435*	-0.375*	-0.454*
$income_{pc}$	0.838*	0.295*	-0.419*	-0.374*	-0.434*
$educ$	0.854*	0.106	-0.497*	-0.419*	-0.500*
$comp_{facility}$	-0.542*	-0.024	0.243*	0.242*	0.252*
$comp_{service}$	0.218	0.050	-0.252*	-0.182	-0.243*
	$speed$	$income_{pc}$	$educ$	$comp_{facility}$	$comp_{service}$
$speed$	1.000				
$income_{pc}$	0.647*	1.000			
$educ$	0.626*	0.767*	1.000		
$comp_{facility}$	-0.416*	-0.500*	-0.486*	1.000	
$comp_{service}$	0.181	0.220	0.272*	0.070	1.000

$*$: Significant at 5% level or higher.

Chapter 4

Tariff Diversity and Competition – Drivers for Broadband Adoption in the European Union

4.1 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 been using the internet in 2010, and in 2015 still an 18% of 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 fibre 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, both seem utterly important to be analyzed to ensure sound regulation and competition policy in this sector.[2]

Broadband customers in the European Union have been used to choosing 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 de-

[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 policy-makers 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.

bate 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 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 Networks in 2016 was subject to the agreement to refrain from differentiated pricing practices by prohibiting usage-based pricing for seven years.[5] In addition, universal service obligations sometimes explicitly prohibit to differentiate 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

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

[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).

can be used to incentivize broadband subscription for the first time.[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, geographic, 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. Currently it 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 their wider coverage, their reputation or the incumbents' concerns about the price-squeeze tests set by competition authorities.[9]

[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 fibre-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.

[9]Although retail prices are not a matter of continuing regulatory concerns in the EU anymore, 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.

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 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 diversity of 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. We account for, first, second-degree price discrimination from selling tariffs with different download speeds, varying contract durations, tiered plans or volume- and time-based pricing and, second, 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 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 policy makers should be lenient towards 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: Section 4.2 outlines the empirical strategy and provides a detailed description of the dataset. Results are presented in Section 4.3, Section 4.4 concludes.

4.2 Model specification and data

4.2.1 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

[10] Note that the analysis does not directly test the effect of UBP versus flat rate pricing, as 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 Section 4.3.2.

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

$$fbb\_sub_{it} = \alpha_0 + \beta_0 fbb\_sub_{i(t-1)} + \gamma^{'}\mathbf{T}_{it} + \delta^{'}\mathbf{C}_{it} + \varphi^{'}\mathbf{X}_{it} + \theta_i + \lambda_t + \epsilon_{it}, \quad (4.1)$$

where *fbb_sub* denotes the number of broadband subscriptions. β_0 measures endogenous growth in terms of network effects. If the process is stationary, it holds that $|\beta_0| < 1$. $\mathbf{T}_{it}$, $\mathbf{C}_{it}$, and $\mathbf{X}_{it}$ are vectors of tariff characteristics, market structure as well as demand and costs controls, respectively. Equation (4.1) also contains country-specific effects, θ_i, and period effects, λ_t, to control for unobserved heterogeneity across countries and periods, plus an unobservable error term, ϵ_{it}.

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.

[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 available upon request.

In $\mathbf{C}_{it}$ the following market structure related variables are subsumed: (i) the intensity of facilities-based competition, (ii) the degree of service-based competition, and (iii) 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 enabled to connect 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.

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, θ_i, and the associated omitted-variable bias by applying a first-difference transformation.[14]

[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 Equation (4.1) 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

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 to use external as well as internal instruments. Internal instruments are lags of the independent, but potentially endogenous, variables. We employ lagged levels as instruments for (i) the lagged dependent variable, (ii) all price-related variables (prices, diversity measures, and income), and (iii) 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 (1996) based on neighboring effects. This type of instrument is applied for the retail price as well as 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.

cannot be present. For brevity, results of the Maddala-Wu unit root test are not reported but available upon request.

4.2.2 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 'Triple-play 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 deflated using the consumer price index. All price-related variables, the numbers of subscribers, and the population size are expressed in logarithms in Equation (4.1) in order to be interpreted as elasticities. Summary statistics in levels are stated in Table 4.1 and a detailed description of the dataset, including the variables used for robustness checks, is provided in Table A4.2.

Fixed broadband adoption is represented as the number of active retail subscribers, constituting the sum of actively used DSL, cable modem, residential fibre, 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

[15] Analysys Mason's 'Tripleplay pricing study' is an international benchmarking survey covering DSL, cable modem, and residential FTTB-based multi-play 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 A4.1. 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 4.1: Summary statistics

Variable	Measured in	Mean	Std. Dev.	Min.	Max.	N
fbb_sub	Subscribers	4716463	5896244	32000	26902000	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	12618.30	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	24063292	25343032	1327439	82534176	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	1400657284	1596697482	55694072	5617589760	311
inter_high	0/1	0.66	0.47	0	1	324
mobile	Subscribers	901478	1237031	7535	6175000	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

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 tariffs. Since there is no information available about 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 to disentangle 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, fibre as well as all other fixed broadband technologies and is denoted by *hhi_inter*. Service-based competition,

[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 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 7 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%.

hhi_intra, is calculated as the HHI between the incumbent's 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.

4.3 Empirical results

Estimation results from the baseline specification, incorporating the different measures of tariff diversity, are presented in Table 4.2. 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

[20] Note that the information presented covers only 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.

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.

4.3.1 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 fibre-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

[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 γ_i, δ_i, and φ_i, the long-run elasticities can be easily obtained as the fraction of the coefficient and the "speed of diffusion", $1 - \beta_0$.

[22] Considering the number of DSL, cable, and fibre 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

Table 4.2: 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 χ^2-stat	80.65	76.68	75.48	84.24	85.39
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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity.

prices, but still noticeable. A 10% increase in tariff diversity, results on average in nearly 50,000 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 seems thus 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%. An European average of $\overline{fms} = 22.1\%$ suggests that the

effect on fibre. The latter at least suggests that price discrimination does not slow down NGA adoption.

[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 fibre-based technologies given that its demand is still modest in many countries.

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]

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.

4.3.2 Robustness checks

This section presents additional estimations which confirm the findings from the previous section (see Tables A4.3–A4.7 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 observa-

[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 cut the cord. Given the significant decline in the number of fixed line telephony subscribers, some countries went from "not 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 towards 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 the escape competition prevailed in all years, however, closely approaching the estimated optimum.

[25] Variable descriptions can be found in Table A4.2.

tions with a quarterly income per capita above 7,000 euro. As can be seen in Table A4.3, the results do not change qualitatively.

Second, additional dimensions of fixed broadband plans are scrutinized. Table A4.4 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 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 A4.5). 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,

[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 includes mobile services.

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 A4.6). 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 fibre 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

[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).

European Commission's intention to cut down the regulation on unbundled access and to promote facilities-based competition seems therefore to be the appropriate policy for regulators (see, also Bourreau and Doğan, 2006).

Fifth, and finally, the estimations in Table A4.7 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 an 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 an 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 an U-shape 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, rising the question whether any fixed-broadband technologies, including fibre-based broadband, which is currently considered the main infrastructure for high-speed internet, can compete with mobile broadband in the long-run.

4.4 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

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

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.

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.

Bibliography

Arellano, M. and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, 58(2):277–297.

Arellano, M. and Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, 68(1):29–51.

Armstrong, M. and Vickers, J. (2001). Competitive price discrimination. *RAND Journal of Economics*, 32(4):1–27.

Barth, A.-K. and Heimeshoff, U. (2014). Does the growth of mobile markets cause the demise of fixed networks? – Evidence from the European Union. *Telecommunications Policy*, 38(11):945–960.

Bauer, J. M., Madden, G., and Morey, A. (2014). Effects of economic conditions and policy interventions on OECD broadband adoption. *Applied Economics*, 46(12):1361–1372.

Bauer, J. M. and Wildman, S. S. (2012). The economics of usage-based pricing in local broadband markets. Michigan State University, East Lansing.

Blundell, R. and Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1):115–143.

Borenstein, S. (1985). Price discrimination in free-entry markets. *RAND Journal of Economics*, 16(3):380–397.

Bouckaert, J., van Dijk, T., and Verboven, F. (2010). Access regulation, competition, and broadband penetration: An international study. *Telecommunications Policy*, 34(11):661–671.

Bourreau, M. and Doğan, P. (2006). 'Build-or-buy' strategies in the local loop. *The American Economic Review*, 96(2):72–76.

Briglauer, W. (2014). The impact of regulation and competition on the adoption of fiber-based broadband services: Recent evidence from the European Union member states. *Journal of Regulatory Economics*, 46(1):51–79.

Bruno, G. S. (2005a). Approximating the bias of the LSDV estimator for dynamic unbalanced panel data models. *Economics Letters*, 87(3):361–366.

Bruno, G. S. (2005b). Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *The Stata Journal*, 5(4):473–500.

Calzada, J. and Martínez-Santos, F. (2014). Broadband prices in the European Union: Competition and commercial strategies. *Information Economics and Policy*, 27:24–38.

Cava-Ferreruela, I. and Alabau-Muñoz, A. (2006). Broadband policy assessment: A cross-national empirical analysis. *Telecommunications Policy*, 30(8-9):445–463.

Cincera, M., Dewulf, L., and Estache, A. (2014). How much does speed matter in the fixed to mobile broadband substitution in Europe? iCite Working paper 10.

Czernich, N., Falck, O., Kretschmer, T., and Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal*, 121(552):505–532.

Denni, M. and Gruber, H. (2007). The diffusion of broadband telecommunications in the U.S – The role of different forms of competition. *Communications & Strategies*, 68:139–157.

Distaso, W., Lupi, P., and Manenti, F. M. (2006). Platform competition and broadband uptake: Theory and empirical evidence from the European Union. *Information Economics and Policy*, 18(1):87–106.

European Parliamentary Research Service (2015). Broadband infrastructure – Supporting the digital economy in the European Union. European Parliament, Brussels, Belgium.

Eurostat (2015). Individuals who have never used the internet. Technical report, Eurostat.

Galperin, H. and Ruzzier, C. A. (2013). Price elasticity of demand for broadband: Evidence from Latin America and the Caribbean. *Telecommunications Policy*, 37(6-7):429–438.

Garcia-Murillo, M. (2005). International broadband deployment: The impact of unbundling. *Communications & Strategies*, 57:83–105.

Gruber, H. and Koutroumpis, P. (2013). Competition enhancing regulation and diffusion of innovation: The case of broadband networks. *Journal of Regulatory Economics*, 43(2):168–195.

Grzybowski, L. (2014). Fixed-to-Mobile Substitution in the European Union. *Telecommunications Policy*, 38(7):601–612.

Grzybowski, L. and Verboven, F. (2016). Substitution between fixed-line and mobile access: The role of complementarities. *Journal of Regulatory Economics*, 49(2):113–151.

Gulati, G. J. and Yates, D. J. (2012). Different paths to universal access: The impact of policy and regulation on broadband diffusion in the developed and developing worlds. *Telecommunications Policy*, 36(9):749–761.

Hamilton, J. D. (1994). *Time Series Analysis*. Princeton University Press.

Haucap, J., Heimeshoff, U., and Lange, M. R. J. (2016). The impact of tariff diversity on broadband penetration – An empirical analysis. *Telecommunications Policy*, 40(8):743–754.

Hausman, J. A. (1996). *Valuation of New Goods under Perfect and Imperfect Competition*, pages 207–248. University of Chicago Press.

Heatley, D. and Howell, B. E. (2010). Structural separation and prospects for welfare-enhancing price discrimination in a new ‘natural monopoly’ network: comparing fibre broadband proposals in Australia and New Zealand. New Zealand Institute for the Study of Competition and Regulation, Wellington, New Zealand.

Höffler, F. (2007). Cost and benefits from infrastructure competition. Estimating welfare effects from broadband access competition. *Telecommunications Policy*, 31(6-7):401–418.

Howell, B. E. (2008). The role of pricing structure in telecommunications technology diffusion. New Zealand Institute for the Study of Competition and Regulation, Wellington, New Zealand.

ITU and UNESCO (2013). The state of broadband 2013: Universalizing broadband.

Kim, J., Bauer, J. M., and Wildman, S. S. (2003). Broadband uptake in OECD countries: Policy lessons from comparative statistical analysis. SSRN Scholarly Paper, Rochester, NY.

Klein, B. (2008). Price discrimination and market power. In Collins, W. D., editor, *Issues in Competion Law and Policy*, volume 2, chapter 41, pages 977–996. American Bar Association Section of Antitrust Law.

Kongaut, C. and Bohlin, E. (2014). Unbundling and infrastructure competition for broadband adoption: Implications for NGA regulation. *Telecommunications Policy*, 38(8-9):760–770.

Lange, M. R. J. and Saric, A. (2016). Substitution between fixed, mobile, and Voice over IP telephony – Evidence from the European Union. *Telecommunications Policy*, 40(10-11):1007–1019.

Lee, S., Marcu, M., and Lee, S. (2011). An empirical analysis of fixed and mobile broadband diffusion. *Information Economics and Policy*, 23(3-4):227–233.

Lin, M.-S. and Wu, F.-S. (2013). Identifying the determinants of broadband adoption by diffusion stage in OECD countries. *Telecommunications Policy*, 37(4-5):241–251.

Lyons, D. (2013). Internet policy's next frontier: Usage-based broadband pricing. *Federal Communications Law Journal*, 66(1):1–44.

McAfee, R. P. (2008). Price discrimination. In Collins, W. D., editor, *Issues in Competion Law and Policy*, volume 1, chapter 20, pages 465–484. American Bar Association Section of Antitrust Law.

McAfee, R. P., Mialon, H. M., and Mialon, S. H. (2006). Does large price discrimination imply great market power? *Economics Letters*, 92(3):360–367.

Nardotto, M., Valletti, T., and Verboven, F. (2015). Unbundling the incumbent: Evidence from UK broadband. *Journal of the European Economic Association*, 13(2):330–362.

Nevo, A., Turner, J. L., and Williams, J. W. (2016). Usage-based pricing and demand for residential broadband. *Econometrica*, 84(2):411–443.

Nickell, S. J. (1981). Biases in dynamic models with fixed effects. *Econometrica*, 49(6):1417–1426.

Odlyzko, A., Arnaud, B. S., Stallman, E., and Weinberg, M. (2012). Know your limits: Considering the role of data caps and usage based billing in internet access service. Public Knowledge, White Paper.

OECD (2008). Broadband growth and policies in OECD countries.

Posner, R. A. (1976). *Antitrust Law: An Economic Perspective*. University of Chicago Press.

Röller, L.-H. and Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *The American Economic Review*, 91(4):909–923.

Roodman, D. (2007). How to do xtabond2: An introduction to 'difference' and 'system' GMM in Stata. Center for global development, Washington, DC.

Spiegler, R. (2006). Competition over agents with boundedly rational expectations. *Theoretical Economics*, 1(2):207–231.

Varian, H. R. (1989). Price discrimination. In Schmalensee, R. and Willig, R. D., editors, *Handbook of Industrial Organization, Handbook in Economics*, volume 10, pages 597–654. North-Holland.

Wallsten, S. and Riso, J. L. (2010). Residential and business broadband prices: Part 1: An empirical analysis of metering and other price determinants. Technology Policy Institute, Washington, DC.

Ward, M. R. and Woroch, G. A. (2010). The effect of prices on fixed and mobile telephone penetration: Using price subsidies as natural experiments. *Information Economics and Policy*, 22(1):18–32.

Appendix

Table A4.1: 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 A4.2: Variables description and source

Variable	Description	Source
fbb_sub	Number of active retail broadband subscribers, including DSL, cable, fibre, 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, fibre, and other fixed broadband connections.	Analysys Mason ('Telecoms Market Matrix')
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 postpaid, excluding customers who have not used their mobile account for more than three 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 fibre 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 A4.3: GDP per capita $\geq$ 7,000 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 χ^2-stat	62.51	66.26	55.16	72.14	67.51
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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
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 UK.

Table A4.4: 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)
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 χ^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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity.

Table A4.5: 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)
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 χ^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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity.

Table A4.6: 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)
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 χ^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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity.

Table A4.7: 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)	
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 χ^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.
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
All regressions include a constant as well as a linear and squared time trend which are not reported for brevity.

Part II

Experimental Economics

Chapter 5

Demand Shifts Due to Salience Effects: Experimental Evidence

Co–authored by Markus Dertwinkel–Kalt, Katrin Köhler, and Tobias Wenzel

5.1 Introduction

This paper studies consumers' choices in markets with vertical product differentiation. Decisions between goods and services which are differentiated in price and quality are widespread. For example, in grocery or electronics stores consumers choose between various types of vertically differentiated goods on a frequent basis, e.g., manufacturer's brands versus home brands or simple cellular phones versus multifunctional smart phones. Given its ubiquity, understanding the underlying evaluation criteria yields important implications for commercial decisions like the range of products produced and for marketing purposes, as well as for related fields such as psychology and consumer decision research in economics (Azar, 2011).

Suppose a consumer has to choose from a set of goods which are characterized by the attributes *price* and *quality*. Standard theory requires that the consumer evaluates the different options separately and chooses the option which maximizes her utility. In contrast, salience theory (Bordalo et al., 2013; henceforth BGS) predicts context-dependent choices. A consumer's attention is drawn either to a good's price or to a good's quality, depending on which attribute is more salient, i.e. differs most from the average level among all options which come to the consumer's mind. In this paper we study choices between vertically differentiated products in a laboratory experiment, thereby providing a first test of salience theory.

In general, salience theory (Bordalo et al., 2012a,b, 2013) states that agents overemphasize especially salient features of choices and underrate less prominent, but possibly important aspects. This assumption is supported by psychological evidence suggesting that an agent's attention is limited and therefore allocated to outstanding features (Taylor and Thompson, 1982; Kahneman, 2011). Regarding decision making under risk, salience theory provides an alternative rationale for violations of expected utility theory which have previously been explained by prospect theory (Bordalo et al., 2012b). With respect to riskless decision making, it can explain many violations of rational choice in the domain of consumer choice, such as endowment (Bordalo et al., 2012a) or decoy effects (Bordalo et al., 2013). Thus, salience theory provides a better understanding for a broad variety of cognitive biases and puzzles via the assumption that agents' attention is focused on outstanding features.

Formally, salience theory is built on two main assumptions: *ordering* and *diminishing sensitivity*. *Ordering* states that an attribute is the more salient the more it differs from the attribute's average level among all options in a given choice context. For instance, a good's price becomes more salient the further it is away from the average price. *Diminishing sensitivity*, as a core feature of human perception in general (Weber's law) and of prospect theory in particular (Kahneman and Tversky, 1979), states that by uniformly increasing the value of an attribute for all goods, the salience of this attribute is reduced. Thus, for example, a generally higher price level makes prices less salient.

The following example by BGS illustrates how purchase decisions between two vertically differentiated products may reverse if the general price level increases. Suppose a consumer intends to buy a red wine at a wine store. She has the choice between an *Australian shiraz* for $10 and a *French syrah* for $20, knowing that she likes the French wine better. As prices in the wine store are modest, the $10 price difference is noticeable. In this context prices are salient, and the consumer opts for the cheaper Australian wine. A few weeks later she visits a restaurant where again both wines are on display. As expected, both wines are marked up by an additional amount of $40, making the price difference of $10 less prominent (due to diminishing sensitivity). Thus, in the restaurant the French syrah seems to be a better deal and the consumer decides to buy a bottle of this wine.

In the preceding example, the consumer's price expectations coincided with the actual prices. As expected, the price level was low in the store and high in the restaurant. Imagine that, in contrast, the consumer expected low prices or was at least unsure whether the price level would be low or high, but then faced high prices (we say that prices are *unexpectedly* high). In such non-deterministic settings, not just the differences between the available options attract the consumer's attention, but also the surprising features of the choice context. Thus, an attribute's salience also depends on how much its actual realization differs from prior expectations, that is, the reference price is not just the average price of all available options, but it is also affected by the consumer's expectation of the price level. If prices are unexpectedly high, the consumer finds prices to be salient. Therefore, she is less likely to choose a high-quality product than if prices where expectedly high. This effect is driven by *ordering*: if a consumer takes not only high, but also low price levels into consideration, the reference price is reduced, thereby rendering high prices more salient. Concerning the example above, a consumer going to a store and being surprised by restaurant prices is hypothesized not to go for the high-class wine, but for the budget option. As a consequence, at expectedly high prices Bordalo et al. (2013) predict that sensitivity to prices is low, while it is higher after unexpected price hikes.

In a laboratory experiment with real consumption decisions, this paper tests two central and distinctive predictions of salience theory with respect to decision making between vertically differentiated products: (1) a higher expected price level for both products shifts demand toward the more expensive, high-quality product and (2) demand for the high-quality product is larger if the price level is expectedly high than if it is unexpectedly high.

In our experiment, participants had to choose between a more expensive, fast internet connection (the high-quality product) and a cheaper, slow internet connection (the low-quality product). They were endowed with a lump sum from which the costs for their purchase were deducted.[1] We controlled for participants' expectations by sending out an information email a couple of days prior to the experiment. In this email the experiment was described and the prices of the two options were announced.

We compare choices in a situation where the actual price level is low (LP-treatment) with a situation where all prices are marked up by the same amount (HP-treatment). In both treatments, the announced prices in the information email were identical to the actual prices faced in the experiment. In order to test for the role of expectations, we ran an additional treatment in which subjects were unsure

[1] There are further studies which implemented real consumption in the laboratory. For instance, internet access has also been used by Pagel and Zeppenfeld (2013) and Houser et al. (2010), whereas Brown et al. (2009) and Jimura et al. (2009) have incorporated beverage rewards. Sippel (1997) offered a variety of goods which could be consumed (snacks, juices, different media).

about the price level (UHP-treatment). In this treatment participants received an information email listing both the prices from the LP- and the HP-treatment, while they faced the high price level from the HP-treatment in the experiment.[2]

We find strong support for the predictions of salience theory. First, we detect that in the HP-treatment the share of subjects opting for the premium product is significantly larger than in the LP-treatment. Second, there is a significant difference between choices in an environment with an expectedly and an unexpectedly high price level, pointing to the importance of controlling for expectations. In particular, we find that when faced with unexpectedly high prices in the UHP-treatment, subjects are less likely to choose the high-quality product than in the HP-treatment.

Our study contributes to the literature in several ways. We test for the fundamentals of salience theory in a controlled and incentivized laboratory experiment with real consumption decisions. We focus on two aspects: the effect of increasing the price level and the effect of price surprises on choices. This has two appeals. First, the predictions regarding our treatments differ widely across recent behavioral papers and thus allow us to assess the validity of various approaches. While several theories can explain at most one finding, salience theory as outlined in BGS is, at least to our knowledge, the only theory that is in accordance with our two main findings in one coherent framework. We elaborate this further in Section 5.5. Second, those treatments are novel additions to the literature. As far as we know there has been no experiment that studies the effects of price surprises on choices. Other predictions by salience theory (such as decoy and compromise effects), on the contrary, have been studied and supported extensively in the literature (Highhouse, 1996; Herne, 1999).

Up to now, there are only a few studies which have empirically tested novel predictions by salience theory. In a laboratory experiment, Dertwinkel-Kalt and Köhler (2016) test for the reverse endowment effect for bads as predicted in Bordalo

[2]Ideally, a test for the role of expectations would include a treatment in which subjects hold wrong expectations such that they do not expect to find the factual prices with any positive probability. We abstain from such a treatment in order to avoid deceiving subjects. Instead of providing erroneous information ex ante, we provided a list of feasible prices, thereby expanding the set of prices the subjects consider to be possible.

et al. (2012a). More directly related to our setup, Azar (2010) conducts a field experiment where differentiated versions of bagels (with and without cream cheese) are sold to students. Testing a model of relative thinking (Azar, 2007), the author implements two treatments with different price levels, but does not find a significant shift in demand. While Azar (2010) does not control for price expectations, we show that demand shifts from low- to high-quality goods occur only if consumers are not surprised by unexpectedly high prices. Hastings and Shapiro (2013) investigate the effect of unexpected price shifts on consumer choices in the market for gasoline. In line with salience theory, they find that an unexpected uniform price increase induces agents to shift toward cheaper, lower octane gasoline. Unlike our study, however, Hastings and Shapiro (2013) need to impose strong assumptions on the prices agents have on their mind when making a purchase decision.

The remainder of the paper is organized as follows. Section 5.2 introduces salience theory and its main predictions regarding our setup. Section 5.3 describes the experimental design and derives the hypotheses before we present our results in Section 5.4. In Section 5.5 we review alternative theories and relate them to our experimental findings. We explain how our study contributes to the literature in Section 5.6 and, finally, Section 5.7 concludes.

5.2 The model

We outline salience theory as presented in BGS. Carefully delineating the role of expectations for the predictions made by salience theory, we illustrate that salience effects can induce different choices in a high-price compared to a low-price setting. The main ingredient of the model is that decision makers do not evaluate options according to true consumption utilities, but overweight the salient attribute of an option.

A decision maker chooses from a finite choice set $\mathfrak{C} = \{(q_k, p_k) \in \mathbb{R}^2_+ | 1 \leq k \leq N\}$ of $N > 1$ vertically differentiated products, where each good $k := (q_k, p_k)$ is described by its quality level q_k and its price p_k. In the absence of salience effects, a consumer values good k with a linear utility function which assigns equal weights to its two attributes,

$$u(k) \ = \ q_k \ - \ p_k. \tag{5.1}$$

If an agent's decision making is affected by salience, she does not maximize Equation (5.1) but overweights the attribute which is more salient. Salience is assessed via a *salience function* $\sigma : \mathbb{R}^2 \to \mathbb{R}_+$ which is symmetric and continuous and has the following two key properties: It obeys *ordering*, that is, $\sigma(x+\mu\epsilon, y-\mu\epsilon') > \sigma(x,y)$ for $\mu = sgn(x-y)$ and $\epsilon, \epsilon' \geq 0$ with $\epsilon + \epsilon' > 0$, and it exhibits *diminishing sensitivity*, that is, $\sigma(x+\epsilon, y+\epsilon) < \sigma(x,y)$ for all $\epsilon > 0$. For a salience function σ and a choice set $\mathfrak{C}$, a product k's price is more salient the larger the value $\sigma(p_k, \overline{p})$ is, with $\overline{p} := \sum_k p_k/N$. Analogously, k's quality is the more salient the larger $\sigma(q_k, \overline{q})$ is, with $\overline{q} := \sum_k q_k/N$. We say that product k's price is salient if $\sigma(p_k, \overline{p}) > \sigma(q_k, \overline{q})$ holds, its quality is salient if $\sigma(p_k, \overline{p}) < \sigma(q_k, \overline{q})$ and both are equally salient if $\sigma(p_k, \overline{p}) = \sigma(q_k, \overline{q})$.

The outlined properties of the salience function capture two essential features of sensory perception (Bordalo et al., 2012b). First, according to ordering, a product's price (quality) is the more salient the more it stands out, put differently, the more it differs from the average price $\overline{p}$ (the average quality $\overline{q}$) in $\mathfrak{C}$. Second, diminishing sensitivity implies that the saliency of a good's attribute decreases if the value of that attribute uniformly increases for all items in $\mathfrak{C}$ (Weber's law of sensory perception). For instance, a good's price becomes less salient if all prices are increased by a uniform amount.

An agent's susceptibility to salience is captured by the parameter $\delta \in [0,1]$ that denotes to which extent the relative weights on the attributes are distorted. Formally, when making her decision, the agent places the multiplicative weight $2/(1+\delta) \geq 1$ on the more salient and $2\delta/(1+\delta) \leq 1$ on the less salient attribute. The smaller δ is the more the decision weights are distorted in favor of a product's salient attribute. The limit case of a rational consumer who maximizes (5.1) is characterized by $\delta = 1$. In the following we assume that the agent is susceptible to the salience bias, thus $\delta < 1$. We denote her corresponding distorted utility function with $u^s(\cdot)$.

To investigate how changes in the price level can induce choice reversals, we show that a higher price levels affect the way a consumer values a product. Suppose that for product k the price is salient, that is, $\sigma(q_k, \overline{q}) < \sigma(p_k, \overline{p})$, such that

$$u^s(k) \;=\; \frac{2\delta}{1+\delta}\, q_k \;-\; \frac{2}{1+\delta}\, p_k. \tag{5.2}$$

Now assume that all prices are uniformly shifted upward by an amount $\Delta > 0$, such that the average price equals $\overline{p}+\Delta$. Due to diminishing sensitivity, product k's price becomes less salient the larger the price shift Δ is. For a sufficiently large Δ, the product's quality may eventually become salient such that $\sigma(q_k, \overline{q}) > \sigma(p_k+\Delta, \overline{p}+\Delta)$ holds. In this case, the uniform price shift Δ makes k's quality salient and the decision maker evaluates the product as

$$u^s(k^{\Delta}) \;=\; \frac{2}{1+\delta}\, q_k \;-\; \frac{2\delta}{1+\delta}\, (p_k + \Delta), \tag{5.3}$$

where $k^{\Delta} := (q_k, p_k + \Delta)$ denotes good k at the increased price level.

Expected price shifts. Suppose there are two vertically differentiated products $k \in \{1, 2\}$ with $q_1 < q_2$ and $p_1 < p_2$. Presuming that these two products lie on a rational indifference curve with $q_k - p_k = c > 0$ for $k \in \{1, 2\}$,[3] the price is salient for both goods as

$$\sigma(q_k, \overline{q}) = \sigma(p_k + c, \overline{p} + c) < \sigma(p_k, \overline{p})$$

holds, such that the low-quality good is chosen.[4] There exists a threshold markup $\Delta^* > 0$ at which prices and quality are equally salient. For any $\Delta < \Delta^*$, the price remains salient for both products such that the low-quality product is chosen, while for any $\Delta > \Delta^*$ quality is overweighted and the consumer chooses the high-quality product. In particular, we have $\Delta^* = c$. Provided that $\sigma(p_k, \overline{p}) > \sigma(q_k, \overline{q})$

[3] We adopt the assumption by BGS that the goods lie on a rational indifference curve merely for illustrative purposes. Whenever the salience distortion outweighs the objective gap between the products, a price shift can reverse choices. Thus, the following predictions still hold if the agent strictly prefers one of the products.

[4] We ensure that the decision maker chooses one alternative by assuming that she receives a utility of $-\infty$ if she does not consume.

and $\sigma(p_k + \Delta, \overline{p} + \Delta) < \sigma(q_k, \overline{q})$, salience theory hypothesizes that a uniform price increase Δ shifts demand toward the high-quality good. Thus, an agent's price sensitivity crucially depends on the price level.

Prediction 1 *Suppose there are two vertically differentiated products and the low-quality product is sold at a lower price. If the general price level is sufficiently low, the agent chooses the low-quality product. If the general price level is sufficiently high, the agent chooses the high-quality product.*

Due to diminishing sensitivity fixed price differences loom the smaller the larger the general price level is. Therefore, subjects are more willing to pay a fixed price difference in order to obtain the better quality at a high than at a low price level.

Unexpected price shifts. In the previous analysis, the agent compares a product against those alternatives which are indeed available. If, however, she expects to find alternatives which are not available when she makes her consumption decision, she may evaluate each option not only within her actual choice set, $\mathfrak{C}$, but within the set comprising the actual and expected offers. We call this comprehensive set the agent's *consideration set* C. For instance, if she expects several price levels to be feasible, then her consideration set consists of the products at their actual and at their expected price level.

Consider again the two vertically differentiated products (q_1, p_1) and (q_2, p_2) with $q_1 < q_2$ and $p_1 < p_2$ and scrutinize the following three scenarios. First, the general price level is low and consumers expected it to be low, that is, for each consumer the consideration set equals the choice set (scenario LP). We denote this as $C^{LP} := \mathfrak{C}^{LP} = \{(q_1, p_1), (q_2, p_2)\}$. Second, the general price level is high and consumers expected it to be high (scenario HP) such that $C^{HP} := \mathfrak{C}^{HP} = \{(q_1, p_1 + \Delta), (q_2, p_2 + \Delta)\}$ holds for some $\Delta > 0$. Third, suppose that consumers expected both price levels to be feasible (scenario UHP). Denote the (exogenous) probability with which the agent expects the low price level $p_L \in [0, 1]$. Then, the low-quality product's expected price equals

$$p_1^e := p_L \, p_1 + (1 - p_L)(p_1 + \Delta)$$

and the high-quality product's expected price is given by

$$p_2^e := p_L\, p_2 + (1 - p_L)(p_2 + \Delta).$$

Denote $\mathfrak{C}^e := \{(q_1, p_1^e), (q_2, p_2^e)\}$. Thus, an agent's consideration set is given by

$$C^{UHP} := \mathfrak{C}^{HP} \cup \mathfrak{C}^e = \{(q_1, p_1 + \Delta), (q_2, p_2 + \Delta), (q_1, p_1^e), (q_2, p_2^e)\}.$$

Within C^{UHP}, the average price is (weakly) lower than within C^{HP}, causing the high-quality product's price to be more salient within C^{UHP} than within C^{HP}. In particular, if the price of the high-quality product is salient in UHP while its quality is salient in HP, then the agent's valuation of this product is lower in UHP than in HP. This yields the prediction that consumers are less inclined to choose the high-quality product if the price level is unexpectedly high than if it is expectedly high.

Formally, the average price within C^{UHP} equals $\overline{p} + (1 - p_L/2)\Delta$ with $\overline{p} = (p_1 + p_2)/2$. Therefore, salience of the high-quality product's price in UHP is given by $\sigma(p_2 + \Delta, \overline{p} + (1 - p_L/2)\Delta)$ while in HP it is given by $\sigma(p_2 + \Delta, \overline{p} + \Delta)$. According to the ordering property, the high price is more salient in UHP than in HP for all $\Delta > 0$ as long as $p_L > 0$. Thus, suppose that in HP the high-quality product's quality is salient while in UHP its price is salient. Then the high-quality product is valued as

$$\begin{aligned} u^s(k^\Delta, C^{UHP}) &= \frac{2\delta}{1+\delta}\, q_k - \frac{2}{1+\delta}\,(p_k + \Delta) \\ < u^s(k^\Delta, C^{HP}) &= \frac{2}{1+\delta}\, q_k - \frac{2\delta}{1+\delta}\,(p_k + \Delta). \end{aligned}$$

Prediction 2 *Suppose agents have to choose between two vertically differentiated products (where the low-quality product has a lower price). Consider two scenarios. First, subjects expect high prices and are faced with coinciding high prices. Second, subjects are unsure whether the price level is high or low, but finally face high prices.*

In the second scenario, fewer subjects choose the high-quality product than in the first scenario.

High prices attract more attention if they are partly surprising than if they were entirely expected. That is, having low prices on one's mind renders high prices more salient. As a result, people are less willing to pay a fixed price difference for the better quality if prices are surprisingly high than if they are not.

Note that these two predictions precisely allow to test the key assumptions of salience theory. The first prediction represents a test of diminishing sensitivity. The second tests jointly (a) the assumption that the consideration set (instead of the actual choice set) affects decision making and (b) the ordering property.

5.3 Experimental setup

5.3.1 Experimental design

We invited students to a laboratory experiment where they had to purchase either a fast or a slow internet connection; an outside option was not available (that is, participants could not opt for not using the internet at all). Internet connections were differentiated with respect to quality, given by potential download speeds: While it took around 30 seconds to fully load frequently used websites, such as Facebook or a newspaper site when using the slow internet connection, it only took around five seconds with the fast connection. Participants did not have to complete any tasks but could use the internet at their convenience for the duration of the experiment. Students received a lump sum payment for participating, however, they had to incur a cost for using the internet.

Procedures

First, students received a standard invitation email to our experiment via ORSEE (Greiner, 2004) and registered online. Deviating from the standard procedure, participants received an additional information email a few days prior to the experiment.

This email corresponded largely to the instructions, which were later distributed during the experiment. In particular, the available speeds, the corresponding prices of the two internet connections and the lump sum payment for participation were announced. This information email was used to influence the participants' expectations of the price level for internet access. We outline below how the information email and the instructions differed between the treatments and discuss how it might affect attrition in Section 4.3.[5]

After arriving at the laboratory, participants were randomly assigned to a separated working station equipped with a computer. All screens were switched off at this point. Subjects received the instructions which the experimenter then read aloud. Participants were informed that they had to purchase internet access which they could use at their convenience for 45 minutes. It was not allowed to use any brought items, e.g., smartphones, books or papers. Speakers were not in place and illegal downloads were prohibited during the experiment. The instructions emphasized that the experimenters could not track which pages the subjects browsed during the experiment.

After reading the instructions aloud and answering potential questions in private, subjects received a decision sheet and indicated their choice of either slow or fast internet. Thereafter, computers were set up according to subjects' purchase decisions. After 45 minutes the screens shut down automatically and a final questionnaire was issued to all participants. Finally, subjects received their payment privately.

Treatments and hypotheses

Within this setting we ran three different treatments and used a between-subjects approach to test the hypotheses proposed by salience theory. Table 5.1 gives an overview of the treatments which we explain below.

The first goal of the experiment was to study the effect of an expectedly higher price level on the consumption choices by implementing a low-price (LP) and a high-price (HP) treatment. In the low-price treatment subjects received a fixed endowment of €12, with prices equal to €0.50 for the slow internet and €1.50 for

[5] Appendix A contains an English translation of the information emails and the instructions.

Table 5.1: Overview of the different treatments.

Treatment	Description	Endowment	Prices		Expected	Consideration
			Fast	Slow	prices	set
LP	low prices	12	1.50	0.50	Yes	$\mathfrak{C}^{LP}$
HP	high prices	15	4.50	3.50	Yes	$\mathfrak{C}^{HP}$
UHP	unexpected prices	15	4.50	3.50	No	$\mathfrak{C}^{HP} \cup \mathfrak{C}^{e}$

All prices in Euros.

the fast internet connection. In the high-price treatment, we increased the general price level by €3, the prices for slow and fast internet access corresponded to €3.50 and €4.50, respectively. To rule out any income effects the endowment was adjusted likewise and amounted to €15.

In both treatments, LP and HP, all information contained in the preceding email (in particular, the listed prices) corresponded to those from the instructions distributed during the experiment. Thus, a subject in treatment LP (HP) considers only the two options at their actual prices, such that her consideration set equals $\mathfrak{C}^{LP}$ ($\mathfrak{C}^{HP}$). This allows us to test for quality choices when low and high price levels are expected. From Prediction 1 we derive the following hypothesis:

Hypothesis 1 *In treatment HP a larger share of subjects opt for the fast internet connection than in treatment LP.*

The study's second objective was to analyze how choices are affected if participants' price expectations are not fully met. We therefore ran a third treatment in which participants were unsure whether the price level would be high or low (UHP). In the UHP-treatment, subjects received an information email prior to the experiment, stating that the prices for both internet connections will be either €0.50 for slow and €1.50 for fast internet (corresponding to prices in the LP-treatment) or €3.50 for slow and €4.50 for fast internet access (corresponding to the prices from the HP-treatment) while the lump sum payment corresponded to that of treatment HP (€15). The actual prices in the experiment were equal to those in the HP-treatment.

With this procedure participants were unsure about the prices they would face in the experiment. The idea is that, when making the purchase decision, the subjects have actual and expected prices on their mind. We interpret this treatment as capturing the effects of unexpectedly high price levels. Thus, a subject's consideration set in treatment UHP is given by $\mathfrak{C}^{HP} \cup \mathfrak{C}^{e}$.[6] From Prediction 2 the following hypothesis follows:

Hypothesis 2 *In treatment UHP a smaller share of subjects opt for the fast internet connection than in treatment HP.*[7]

Participants

Sessions were conducted between January and June 2015 at the DICE experimental laboratory at the Heinrich Heine University Düsseldorf. In total, 169 subjects participated, 59 in the HP, 57 in the LP, and 53 in the UHP treatment. Each treatment comprised five sessions, thus adding up to 15 sessions for the three treatments. A session lasted around 60 minutes and subjects earned either €10.50 or €11.50.

5.3.2 Discussion of the experimental design

We now discuss the main features of the design and how they match the assumptions made by salience theory. Furthermore, we outline the advantages of a laboratory experiment compared to a field study.

First, the consumption alternatives in our experiment are clearly vertically differentiated. A fast internet connection is doubtlessly superior to a slow one and, at equal prices, one would expect all subjects to opt for the fast connection. Therefore,

[6]We stay agnostic about the exact probability with which the low price level is expected. As we mention the low price level in the information email, however, we assume that most subjects expect the low price level to occur with *some* probability.

[7] In this stylized rank-based salience model according to which an attribute is either salient or not, choices in UHP and LP should be identical if the price is salient in both treatments. This, however, is an artefact of the rank-based model. Choices in LP and UHP are not predicted to be identical in a richer model with a smooth salience specification according to which weights do not just reflect which attribute is more salient, but also how salient an attribute in fact is. A smooth specification is, for instance, proposed in footnote 9 of Bordalo et al. (2012b).

we can exactly mirror the assumption made in BGS according to which goods are two-dimensional and uniquely defined by their quality- and price-parameters. Another advantage of our implementation is that subjects in our experiment have a clear demand for the products as they are not allowed to use any devices or items during the 45-minute duration of the experiment.

Second, high-price and low-price environments typically attract different classes of consumers. For instance, consumers who buy wines at high-class restaurants and those who buy wines at cheap stores can be expected to be heterogeneous with respect to income and the appreciation of quality. We can exclude such sample biases by randomly assigning subjects to treatments.

Third and most importantly, the design of our experiment allows us to analyze the role of consideration sets and expectations. To the best of our knowledge, we are the first to investigate the subtle difference between expected and unexpected price shifts which plays an important role for consumer choice in salience theory. In the study by Hastings and Shapiro (2013), for example, the empirical results crucially depend on the definition of the consideration sets. In their two specifications, the consideration sets consisted of all price-quality-combinations which were available either during the last week or during the last four weeks. Their results are sensitive to this specification. In our LP- and HP-treatments the consideration sets are explicitly given by the choice sets while in treatment UHP the consideration set is larger as it comprises also the options at their expected prices. Thereby, we can properly control for the consideration set which is a novelty in the empirical literature.

Fourth, by adjusting the endowments between treatments LP and HP, we keep the subjects' income level constant in real terms such that the choices in terms of real payoffs are identical in all three treatments: subjects could either get the high-speed internet and €10.50 or the low-speed internet and €11.50. That is, the differences between the choices that we observe can be attributed to the different frames used in the treatments. Here we have standard economic theory as the clear benchmark, which we could test against, as it cannot explain any shift of demand between the treatments. If endowments stay the same (such that income differs in real terms between the treatments), we would not expect the same choice patterns.

Due to income effects, we would expect fewer choices for the fast internet with a low price level and an endowment of 12 Euro than with a low price level and endowment 15. As a consequence, when comparing HP and LP with identical endowments (say 15) this would contain both salience effects and income effects. We therefore view the adjustment of endowments as the appropriate approach to detect salience effects when comparing HP and LP.

Fifth and finally, we are able to fix the consumption location in our study. Both the high- and the low-quality product yield the same utility in all treatments, while in general high-quality products may provide a higher utility at high-class, pricy locations. Our study eliminates this as an explanation for demand shifts.

5.4 Results

This section presents the experimental results which are summarized in Table 5.2. We start by investigating the effects of an expectedly high price level and compare the treatments LP and HP (Hypothesis 1). Subsequently, we examine the impact of an unexpectedly high price level (or, more precisely, of a high price level when low prices are considered) by comparing HP and UHP (Hypothesis 2). Robustness checks are provided at the end of this section.

Table 5.2: Experimental results

	LP treatment		**HP treatment**		**UHP treatment**	
	Choice		Choice		Choice	
Fast	16	28.1%	27	45.8%	14	26.4%
Slow	41	71.9%	32	54.2%	39	73.6%
# of participants	57		59		53	

5.4.1 Results for an expectedly high price level

We find that in treatment HP the share of subjects opting for the more expensive internet connection is significantly higher than in treatment LP. As can be seen in

Table 5.2, in treatment LP 28.1% (16 out of 57 subjects) choose the fast internet connection while in treatment HP this share increases to 45.8% (27 out of 59 subjects). This effect is quite sizeable: In our setting, a €3 markup on both prices significantly raises the share of the high-quality product by roughly 20 percentage points. With a p-value of 0.025 (one-sided χ^2-test), we can reject the null hypothesis that an expectedly higher price level (weakly) decreases the share of subjects choosing the high-quality product. This is in line with Hypothesis 1:

Result 1 *With an expectedly higher price level, a larger share of subjects opt for the high-quality, more expensive internet connection.*

5.4.2 Results for an unexpectedly high price level

We now contrast the effects of an expectedly and an unexpectedly high price level by comparing the outcomes in the treatments HP and UHP. In compliance with Hypothesis 2, a smaller share of subjects should opt for the fast internet in treatment UHP than in treatment HP. Indeed, our results suggest that subjects' choices depend on their initial expectations of the price level. In treatment HP 45.8% of the subjects (27 out of 59) opt for the fast internet connection, while in treatment UHP only 26.4% of the subjects (14 out of 53) choose the fast internet connection. In treatment UHP a significantly lower share of subjects favors the fast internet connection than in treatment HP ($p = 0.017$, one-sided χ^2-test). Hence, the null hypothesis that, compared to an expectedly high price level, an unexpectedly high price level (weakly) increases the share of subjects opting for the high-quality product can be rejected. Thus, our result accords with Hypothesis 2:

Result 2 *Compared to an expectedly high price level, a lower share of subjects opt for the fast internet connection when facing an unexpectedly high price level.*

Our results suggest that expectedly and unexpectedly high price levels affect choices differently. An expectedly higher price level tends to increase the share of subjects choosing the high-quality, high-price product, while an unexpectedly higher price level does not. Both findings are in line with the predictions made by BGS.

5.4.3 Robustness

In this subsection we assess the robustness of our results. First, we apply a multivariate logit regression model to control for subject characteristics. Second, we analyze whether attrition might impact our results.

Logit estimation is conducted given the binary dependent variable, which equals one if a subject chose the fast internet connection and zero otherwise.[8] The regression analysis allows to control for personal characteristics that might influence subjects' decisions. The included controls are gender and field of study.[9] Table B5.1 (Appendix B) provides summary statistics of all variables. Estimation results for an expectedly and an unexpectedly high price level are presented in Table 5.3.

Table 5.3: Logit regression of opting for the fast internet connection.

Parameter	**(1)**	**(2)**	**(3)**	**(4)**
High Price	0.771***	0.730**	0.771***	0.728**
	(0.326)	(0.401)	(0.320)	(0.358)
Unexpected	-	-	-0.855***	-0.782***
			(0.260)	(0.279)
Controls	no	yes	no	yes
Observations	116	111	169	163

All specifications include a constant.
Robust standard errors at the session level in parenthesis.
One-sided significance level: *: 10%, **: 5%, ***: 1%.

Specifications (1) and (2) use the choice data from the treatments LP and HP to estimate the effect of an expected uniformly higher price level. Specification (1) solely includes the dummy variable *High Price*, which is equal to one if a subject is part of the treatment group with an increased price level (HP treatment). *High Price* is positive and highly significant. Switching from LP to HP results in a 0.77 unit change in the log of the odds for choosing the fast internet. Put differently, the odds of choosing the fast internet connection are 2.2 times (120%) larger in the

[8] Applying OLS yields similar results. However, due to the discrete dependent variable logit is preferred to OLS.

[9] Although we have further information on age and the degree pursued (bachelor vs. master), we abstained from including them as the qualitative results do not change, but sample size is reduced due to missing observations.

HP than in the LP treatment. When controlling for personal characteristics, as in specification (2), the effect is marginally reduced. Being part of the HP treatment increases the log of the odds of choosing the fast internet connection by 0.73 or rather the odds are 108% higher in the HP than in LP treatment. Both results are in line with Result 1.

To determine the difference between an expectedly and an unexpectedly high price level, we include the variable *Unexpected*. *Unexpected* indicates whether the information email announced both price levels (*Unexpected*=1) or the factual prices only (*Unexpected*=0). Columns (3) and (4) report the estimation results, using data from all three treatments. Again, we estimate a model with and without additional controls.[10] In both specifications the coefficients of *Unexpected* are negative at a high significance level. Taking part in UHP instead of HP, leads to a -0.86 (-0.78) unit change in the log of the odds of choosing fast internet. Alternatively, the odds in UHP are 58% (54%) lower than the odds in HP.[11] These findings are consistent with Result 2.

Induced by the non-standard invitation procedure with the upfront information email, attrition might be an issue, i.e., the non-random dropout of invited subjects across treatments. Indeed, show-up rates slightly vary: 84% in LP, 88% in HP and 77% in UHP. However, several pieces of evidence suggest that there is no selection bias. First, the documented show-up rates are comparable to those of other experiments conducted in the same lab (roughly 85%). Second, there is no selection on observables as subject characteristics are balanced across treatments (see Table B1). Third, and in contrast to the recent literature which deals with attrition and selection on unobservables (Behaghel et al., 2009; Jones and Mahajan, 2015), potential explanations why attrition might not be orthogonal to our treatment assignment oppose the effect we observe, that is, higher attrition in UHP. In particular, the earnings in UHP weakly dominate those in LP and HP, suggesting a lower dropout rate in UHP. Expected earnings are even strictly higher for any choice if the subject

[10]Note that none of the included controls is significant in both regressions (2) and (4) and the effect of the main treatment variables (*High Price* and *Unexpected*) does not depend on the selection of controls.

[11]When estimating the model only with data on HP and UHP, results are confirmed.

assigns a positive probability to the low-price scenario. Thus, besides a random effect there seems to be no plausible explanation (e.g., risk aversion) for the slightly lower show-up rate in UHP.

Nevertheless, selection on unobservables cannot be ruled out entirely. Following Behaghel et al. (2009) and Jones and Mahajan (2015), we impose the monotonicity assumption to derive a lower bound on the magnitude of the demand shift. Monotonicity assumes that all subjects showing up in the treatment with the higher attrition rate (UHP) would have also shown up in the treatment with the lower attrition rate (HP). We are interested in the counterfactual decision of the 59 HP-subjects if they had participated in UHP. Denote C_z an indicator variable which is one if and only if a subject showed up in treatment $z \in \{\text{HP, UHP}\}$. Incorporating the method by Jones and Mahajan (2015, Appendix C.2), we obtain $\mathbb{E}(Y_{\text{HP}} - Y_{\text{UHP}}|C_{\text{HP}} = 1) = 0.128 > 0$, where $Y_z = 1$ if the subject chooses fast internet in treatment z and zero otherwise. Thus, the demand shift persists even if we consider this lower bound. Alternatively, we could investigate a worst-case scenario in the spirit of Lee (2009) by aligning the sample sizes. According to the monotonicity assumption, it suffices to enlarge the UHP-sample by six observations working against our effect. Even in this worst-case scenario, the difference between HP and UHP is significant at the 10% level (p=0.094, one-sided χ^2-test). Thus, Result 2 still holds under very conservative assumptions.

5.5 Discussion of alternative theories

Standard economic theory cannot account for the different choice patterns that we observe. As the feasible outcomes are identical in all three treatments, i.e., receiving €10.50 and the high-quality internet or €11.50 and the low-quality internet, standard economic theory does not predict a demand shift. Hence, neither Result 1 nor Result 2 can be explained.

Other behavioral models, such as Kahneman and Tversky (1979), Kőszegi and Rabin (2006), Kőszegi and Szeidl (2013), Bushong et al. (2015), Azar (2007) and Cunningham (2013), can explain parts of our findings, but no model is consistent with both results. Thus, no other model (apart from BGS) can account for Result 1 and Result 2 in one coherent framework.

Prospect theory (Kahneman and Tversky, 1979). Prospect theory hypothesizes that subjects evaluate outcomes with respect to a deterministic, exogenous reference point which typically indicates an agent's status quo. With respect to this reference point, an agent's value function satisfies the properties of diminishing sensitivity and loss aversion, that is, losses are weighted disproportionally compared to gains. In our experiment, the reference point is represented by a two-dimensional vector (r_1, r_2), where r_1 gives the reference earning and r_2 gives the reference quality of the internet connection. As university students typically have access to high speed internet for free (in particular, those living on campus), a sensible reference point is where r_1 equals the announced endowment (€12 in LP and €15 in HP) and r_2 equals the high quality q_H.

Given this reference point, prospect theory can explain Result 1 via diminishing sensitivity: the price difference in LP (1.50 vs. 0.50) feels larger than the same price difference in HP (4.50 vs. 3.50). Hence, choosing the high-quality product is more attractive in HP than in LP. In particular, a decision maker opting for the high-quality product in LP will also opt for it in HP, therefore the share of subjects opting for the high-quality product is larger in HP than in LP.

Prospect theory, however, does not predict different decisions for treatments HP and UHP as the subject's status quo and therefore the reference point is not affected by the information email. In a nutshell, prospect theory can explain Result 1, but not Result 2.

Personal equilibrium (Kőszegi and Rabin, 2006). Kőszegi and Rabin (henceforth: KR) propose a reference-dependent model where an agent is loss averse with respect to an endogenous reference point which is shaped by rational expectations. According to their equilibrium concept of a *personal equilibrium* (PE) expectations are consistent with actual behavior. A *preferred personal equilibrium* selects a PE with the highest expected utility. In deterministic environments, KR prescribe choices which maximize consumption utility (see their Section III). As both options yield exactly the same outcomes in the treatments HP and LP (quality q_H and an income of €10.50 or quality q_L and an income of €11.50), the demand shift between LP and HP cannot be explained by KR.[12]

In order to apply the concept of a personal equilibrium to treatment UHP, each subject has to assign well-defined probabilities to the different price levels. Given that the probability with which the low price level is expected is sufficiently high, KR can explain why few people choose the high-quality option in UHP. The reason is that a subject will rationally expect to go for the low-quality in order to minimize her loss in the price-dimension. Hence, KR can be consistent with Result 2. In Appendix C, we provide a formal analysis for this prediction. If, however, subjects in UHP have no well-defined expectations, but are ambiguous about the occurring price level, KR cannot be applied to treatment UHP as KR require subjects to have clear price expectations. In addition, if the high price level is expected to be distinctly more likely than the low price level, there exist further (preferred) personal equilibria (i.e., one in which subjects choose the high-quality option with probability one, and one in which subjects strictly mix) such that any choice pattern is in line with KR.

Focusing theory (Kőszegi and Szeidl, 2013) and relative thinking (Bushong et al., 2015).

Kőszegi and Szeidl (henceforth: KS) and Bushong et al. (henceforth: BRS) offer two closely related approaches. KS assume that a decision maker overemphasizes those attributes for which the range of choice in choice set $\mathfrak{C}$ is broad, that is, for which her options differ a lot, while she tends to neglect attributes for which the available options are rather similar. In contrast, BRS assume the opposite: a decision maker puts more weight on dimensions where the range of choice is small. More precisely,

[12] For illustration, assume that both goods lie on a rational indifference curve. In a preferred personal equilibrium the agent will expect to choose one of the options with certainty and behave consistently at the second stage. Therefore, in LP and HP two preferred personal equilibria exist and Result 1 remains unexplained.

according to both approaches, an agent values an option $k = (q_k, p_k)$ as

$$u(k) \;=\; w_q\; u_q(q_k) \;-\; w_p\; u_p(p_k), \tag{5.4}$$

where for $x \in \{p, q\}$ function $u_x(\cdot)$ gives a subject's consumption utility in dimension x while weight w_x is a function of the available range in dimension x, that is, $w_q = w(\Delta_q)$ with $\Delta_q := \max_{k\in\mathfrak{C}} u_q(q_k) - \min_{k\in\mathfrak{C}} u_q(q_k)$ and $w_p = w(\Delta_p)$ with $\Delta_p := \max_{k\in\mathfrak{C}} u_p(p_k) - \min_{k\in\mathfrak{C}} u_p(p_k)$. Crucially, KS assume that $w'_x > 0$, while BRS propose that $w'_x < 0$ for $x \in \{p, q\}$.

With utilities linear in price and quality, the price ranges are identical in treatments LP and HP, $\Delta_q = \Delta_p = 4.50 - 3.50 = 1.50 - 0.50$, such that both models cannot account for Result 1.

Regarding the predictions of treatment UHP it is essential to consider how announced, but not available options affect an individual's consideration set and therefore the weights w_x. KS mention such effects, but do not offer a systematic approach how to incorporate them into their setup. BRS, in contrast, consider several approaches. In the following we discuss their preferred one (see Section 4 of their paper), according to which a subject chooses an option before she is certain about its price (that is, for instance, after she has read the information email, but before the actual experiment).[13] Formally, she chooses between lotteries on $\mathbb{R}^K$, that is, her choice set is some $\mathfrak{F} \subset \Delta(\mathbb{R}^K)$. Following BRS the range along dimension p can be defined by

$$\Delta_p(\mathfrak{F}) = \max_{F\in\mathfrak{F}}(E_F[u_p(p_k)] + \frac{1}{2}S_F[u_p(p_k)]) - \min_{F\in\mathfrak{F}}(E_F[u_p(p_k)] - \frac{1}{2}S_F[u_p(p_k)]), \tag{5.5}$$

where $E_F[u_p(p_k)] = \int u_p(p_k)dF(p)$ denotes the decision maker's expectation of $u_p(p_k)$ under F, and $S_F[u_p(p_k)] = \int\int |u_p(p'_k) - u_p(p_k)|dF(p')dF(p)$ the average distance between two independent draws from the distribution. Let $0 < p_L \leq 1$ be the probability with which the low price level is expected and $(1 - p_L)$ the probability of expecting the high price level. Straightforward computations show that the

[13] In our experiment, around 80% of the subjects indicated that they have indeed made their decision immediately after reading the information email.

range of the price dimension in UHP equals $\Delta_p^{UHP} = 1 + 6p_L(1 - p_L)$, which always exceeds the range in HP, that is, $\Delta_p^{HP} = 1$. Thus, BRS predict that prices attract more attention in HP than in UHP such that subjects should be more likely to opt for the high quality in UHP. This contradicts our findings.

To sum up, both KS and BRS cannot account for our results in their original setups.[14] In particular, we can rule out that our findings are driven by relative thinking as proposed in BRS.

Relative thinking (Azar, 2007). Azar's model of relative thinking hypothesizes that both the absolute and the relative price differences matter for product choices. Given vertically differentiated products, consumers are predicted to choose the higher quality product with uniformly higher prices as the relative price increase is lower for the high-quality product. Therefore, relative thinking explains Result 1.[15] As the predictions are independent of the decision maker's expectations, Azar cannot account for the difference between expected and unexpected price increases (Result 2).

Models closely related to Azar (2007), such as Alchian and Allen (1964) and Barzel (1976), predict a higher relative demand for high-quality products in high-price than in low-price environments. This prediction stems from the fact that the price of the premium product relative to the low-quality product is reduced by the existence of fixed costs, such as transportation costs (Alchian and Allen) or unit taxes (Barzel). Taking into account relative prices, demand shifts toward higher-quality products after a price increase. Several empirical papers aimed at testing this hypothesis, with generally mixed results.[16] However, in contrast to BGS and

[14]Note, however, that focusing theory can account for both results if the following two assumptions are added to the model by Kőszegi and Szeidl (2013): first, the utility function satisfies diminishing sensitivity, and second, mentally but not factually available items are admitted to the agent's choice set.

[15]Azar (2010) tests this hypothesis both in a field experiment and in a hypothetical study. While the hypothetical study supports his prediction (see also Azar, 2011), the field results reject it.

[16] Bertonazzi et al. (1983), Borcherding and Silberberg (1978), Nesbit (2007), and Sobel and Garret (1997) find evidence of a demand shift, whereas Coats et al. (2005) and Lawson and Raymer (2006) find no or only moderate support.

the present investigation, none of these papers accounts for the composition of the consideration set such that they cannot explain Result 2.

Comparisons and choice (Cunningham, 2013). Cunningham offers a behavioral theory according to which preferences depend on the current choice set and on the choice set history. His main assumption is that the appreciation for a certain choice dimension (more precisely, the marginal rate of substitution between this and every other dimension) decreases if any element in the history (or the current choice set) increases in absolute value along this dimension.

Concerning our experiment, this theory is consistent with Result 1. As both prices in HP are larger in absolute value, the price dimension attracts less attention than in LP such that subjects are more likely to choose the high quality product in HP than in LP. Cunningham, however, does not offer an unambiguous way of how to include the information email into the framework. In our interpretation of the model the content of the information email is not part of the choice set history and therefore Result 2 is not explained.[17] Thus, Cunningham can account for our first, but not for our second result.

5.6 Discussion

Our experiment and, in particular, our first two treatments HP and LP, are in the spirit of the jacket and calculator puzzle by Tversky and Kahneman (1981) and Thaler (1999). According to this puzzle, people are willing to drive across town to save \$5 on a \$15 calculator while they are not willing to drive across town to save

[17]It should be noted that if one is willing to assume that (i) the content of the information email forms part of the choice set history and (ii) the choice history affects decisions only through the average values observed in the entire history, then Result 2 is also consistent with his theory as the average price is larger in HP than in UHP. Thus, price attracts less attention in HP than in UHP and consequently subjects are more likely to choose the high quality in HP. However, this logic would also imply that individuals are less likely to choose the high-quality product in LP than in UHP as the average price is lower in LP. But this prediction is not consistent with our results as we do not observe significantly different choices between LP and UHP. It should also be noted that Assumption (ii) is criticized, for instance, by Bushong et al. (2015) in footnote 3, where they argue that this assumption can contradict relative thinking in a counter-intuitive manner.

$5 on a $125 jacket. Thus, people seem to value saving a fixed amount the less the higher the base price is ($10 vs. $120).

In contrast to other studies, we exclude the outside option of not buying at all, which allows us to precisely distinguish between relative thinking and *diminishing sensitivity*. Bushong et al. (2015)'s model of relative thinking, for instance, can explain the puzzle only if not buying is an available option. Then, the cost saving seems large if the base price is low as it represents a larger percentage of the overall price range. On the contrary, if the base price is high, the cost saving represents only a small percentage of the overall price range, such that the saving opportunity seems less attractive. By excluding the outside option of not buying, we hold the price range constant between our treatments such that we can rule out relative thinking as the driver of our effect.

Our third and most novel treatment (UHP) extends the jacket and calculator puzzle by showing that not only the base price, but also the expectations of the base price affect price sensitivity. An agent is price-sensitive even at high base prices if she is surprised by the high price level. This treatment allows to test for two assumptions simultaneously: for *ordering* and for the effect of only *mentally available items* on decision making. Especially the test for the latter is novel as it is hard to control for a subject's consideration set outside a controlled laboratory experiment.

We test these fundamentals in a domain where salience theory's predictions are most novel. Alternative predictions, such as decoy and compromise effects, have been documented in different domains (see, e.g., Highhouse, 1996), both in hypothetical and in incentivized experiments (Herne, 1999). For instance, Heath and Chatterjee (1995) provide a meta-analysis which demonstrates that adding decoys to choice sets increases the demand for brands which are similar to the decoys but reduces demand for dissimilar brands.

5.7 Conclusion

This study explores choices between vertically differentiated products in a laboratory experiment with real consumption decisions. We find that decision makers' responses largely depend on whether price levels are expected or not. An expectedly high price level induces more subjects to choose the high-quality product than if subjects were unsure about the actual prices. By analyzing the differential effects of expected and unexpected price hikes, we confirm two central predictions of consumer choice for vertically differentiated products made by salience theory (Bordalo et al., 2013). Furthermore, we review alternative established behavioral theories and find that these theories cannot account for our findings.

Our study provides interesting insights for researchers and practitioners about the decision making of consumers. Given that salience theory predicts that expected upward price shifts can reduce consumers' price sensitivity, it yields a rationale for various observations in the retail sector. For example, our findings explain why suppliers can sustain high margins for premium products in high-price environments where quality is more likely to be overweighted while prices tend to be disregarded.[18]

Moreover, we document that consumers tend to overweight prices when price increases are unexpected. This yields important insights for marketing purposes. For instance, when a retailer is confronted with uniform cost increases (for all its products, e.g., change in quantity taxes), the retailer should not only expect its demand to drop if the change in final consumer prices is unexpected by consumers, but also to expect that demand between high- and low-quality variants will change toward lower quality.

[18] For instance, Dudenhöffer (2014) shows that premium manufacturers in the automotive industry can preserve EBIT margins for each car that are twice as high as those earned by high-volume manufacturers.

Bibliography

Alchian, A. and Allen, W. R. (1964). *University Economics*. Wadsworth.

Azar, O. H. (2007). Relative thinking theory. *Journal of Socio-Economics*, 36(1):1–14.

Azar, O. H. (2010). Does relative thinking exist in real-world situations? A field experiment with bagels and cream cheese. *Economic Inquiry*, 49(2):564–572.

Azar, O. H. (2011). Relative thinking in consumer choice between differentiated goods and services and its implications for business strategy. *Judgment and Decision Making*, 6(2):176–185.

Barzel, Y. (1976). An alternative approach to the analysis of taxation. *Journal of Political Economy*, 84(6):1177–1197.

Behaghel, L., Crépon, B., Gurgand, M., and Le Barbanchon, T. (2009). Sample attrition bias in randomized experiments: A tale of two surveys. Discussion Paper 4162, IZA.

Bertonazzi, E. P., Maloney, M. T., and McCormick, R. E. (1983). Some evidence on the Alchian and Allen theorem: The third law of demand. *Economic Inquiry*, 31(3):383–393.

Borcherding, T. E. and Silberberg, E. (1978). Shipping the good apples out: The Alchian and Allen theorem reconsidered. *Journal of Political Economy*, 86(1):131–138.

Bordalo, P., Gennaioli, N., and Shleifer, A. (2012a). Salience in experimental tests of the endowment effect. *American Economic Review*, 102(3):47–52.

Bordalo, P., Gennaioli, N., and Shleifer, A. (2012b). Salience theory of choice under risk. *Quarterly Journal of Economics*, 127(3):1243–1285.

Bordalo, P., Gennaioli, N., and Shleifer, A. (2013). Salience and consumer choice. *Journal of Political Economy*, 121(5):803–843.

Brown, A. L., Chua, Z. E., and Camerer, C. (2009). Learning and visceral temptation in dynamic savings experiments. *Quarterly Journal of Economics*, 124(1):197–231.

Bushong, B., Rabin, M., and Schwartzstein, J. (2015). A model of relative thinking. Working paper, Harvard University.

Coats, R. M., Pecquet, G. M., and Taylor, L. (2005). The pricing of gasoline grades and the third law of demand. Working paper, Nicholls State University.

Cunningham, T. (2013). Comparison and choice. Working paper, Harvard University.

Dertwinkel-Kalt, M. and Köhler, K. (2016). Exchange asymmetries for bads? Experimental evidence. *European Economic Review*, 82:231–241.

Dertwinkel-Kalt, M., Köhler, K., Lange, M. R. J., and Wenzel, T. (2016). Demand shifts due to salience effects: Experimental evidence. *Journal of the European Economic Association*, forthcoming.

Dudenhöffer, F. (2014). Was die Autobauer an ihren Autos verdienen. CAR-Center Automotive Research, University of Duisburg-Essen.

Greiner, B. (2004). The online recruitment system ORSEE 2.0 - A guide for the organization of experiments in economics. Working paper, University of Cologne.

Hastings, J. S. and Shapiro, J. M. (2013). Fungibility and consumer choice: Evidence from commodity price shocks. *Quarterly Journal of Economics*, 128(4):1449–1498.

Heath, T. B. and Chatterjee, S. (1995). Asymmetric decoy effects on lower-quality versus higher-quality brands: Meta-analytic and experimental evidence. *Journal of Consumer Research*, 22(3):268–284.

Herne, K. (1999). The effects of decoy gambles on individual choice. *Experimental Economics*, 2(1):31–40.

Highhouse, S. (1996). Context-dependent selection: The effects of decoy and phantom job candidates. *Organizational Behavior and Human Decision Processes*, 65(1):68–76.

Houser, D., Schunk, D., Winter, J. K., and Xiao, E. (2010). Temptation and commitment in the laboratory. Working Paper 488, Institute for Empirical Research in Economics, University of Zurich.

Jimura, K., Myerson, J., Hilgard, J., Braver, T. S., and Green, L. (2009). Are people really more patient than other animals? Evidence from human discounting of real liquid rewards. *Psychonomic Bulletin & Review*, 16(6):1071–1075.

Jones, D. and Mahajan, A. (2015). Time-inconsistency and saving: Experimental evidence from low-income tax filers. Working Paper 21272, National Bureau of Economic Research.

Kahneman, D. (2011). *Thinking, fast and slow.* Penguin.

Kahneman, D. and Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica*, 47(2):263–292.

Kőszegi, B. and Rabin, M. (2006). A model of reference-dependent preferences. *Quarterly Journal of Economics*, 121(4):1133–1165.

Kőszegi, B. and Szeidl, A. (2013). A model of focusing in economic choice. *Quarterly Journal of Economics*, 128(1):53–104.

Lawson, R. and Raymer, L. (2006). Testing the Alchian-Allen theorem: A study of consumer behavior in the gasoline market. *Economics Bulletin*, 4:1–6.

Lee, D. S. (2009). Training, wages, and sample selection: Estimating sharp bounds on treatment effects. *Review of Economic Studies*, 76(3):1071–1102.

Nesbit, T. M. (2007). Excise taxation and product quality: The gasoline market. *Economic Issues*, 12:1–14.

Pagel, M. and Zeppenfeld, C. (2013). Expectations-based reference-dependent consumption and portfolio choice: Evidence from the lab. Working paper, Columbia Business School.

Sippel, R. (1997). An experiment on the pure theory of consumer's behaviour. *Economic Journal*, 107(444):1431–1444.

Sobel, R. S. and Garret, T. A. (1997). Taxation and product quality: New evidence from generic cigarettes. *Journal of Political Economy*, 105(4):880–887.

Taylor, S. E. and Thompson, S. C. (1982). Stalking the elusive "vividness" effect. *Psychological Review*, 89(2):155–181.

Thaler, R. H. (1999). Mental accounting matters. *Journal of Behavioral Decision Making*, 12:183–206.

Tversky, A. and Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, 211(4481):453–458.

Appendix A: Information emails and instructions

Dear participants,

please read this email carefully! It contains information about the procedure of the experiment on xx/xx/2015, for which you registered.

The experiment is about your willingness to pay for internet access. You have to purchase **high-speed or low-speed internet** which you can use at your convenience during the experiment - please note that it is not possible to buy no internet access at all! For participating in the experiment you will automatically receive a fixed payment of **12 Euro** minus the costs for the selected internet access.

You can use the internet at your convenience during the experiment and you do not have to do any further tasks. Note that the browser will be reset automatically after the experiment - no content will be saved! Neither the experimenters nor other people can reproduce which websites you have visited.

Restrictions: you are not allowed to use the speakers of the computer in order to not disturb other participants, to visit illegal websites or to perform any downloads. Furthermore, you are not allowed to use your own paper, mobile phones or any other printed media or electronic devices.

High-speed internet (regular internet access via the HHU-network) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average less than 5 seconds** to load.

Low-speed internet (restricted internet access) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average about 30 seconds** to load.

The one-time costs for the two alternatives are:

- **High-speed internet: €1.50**
- **Low-speed internet: €0.50**

At the beginning of the experiment you will receive a decision sheet where you have to indicate your choice for one of the two internet alternatives. After you have made your decision, your computer is set up according to your choice and you can use the internet for the next 45 minutes. After 45 minutes you will receive your payment (12 Euro minus the cost for the chosen internet access) and the experiment is finished.

Figure A5.1: Information email for the participants of treatment LP.

Dear participants,

please read this email carefully! It contains information about the procedure of the experiment on xx/xx/2015, for which you registered.

The experiment is about your willingness to pay for internet access. You have to purchase **high-speed or low-speed internet** which you can use at your convenience during the experiment - please note that it is not possible to buy no internet access at all! For participating in the experiment you will automatically receive a fixed payment of **15 Euro** minus the costs for the selected internet access.

You can use the internet at your convenience during the experiment and you do not have to do any further tasks. Note that the browser will be reset automatically after the experiment - no content will be saved! Neither the experimenters nor other people can reproduce which websites you have visited.

Restrictions: you are not allowed to use the speakers of the computer in order to not disturb other participants, to visit illegal websites or to perform any downloads. Furthermore, you are not allowed to use your own paper, mobile phones or any other printed media or electronic devices.

High-speed internet (regular internet access via the HHU-network) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average less than 5 seconds** to load.

Low-speed internet (restricted internet access) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average about 30 seconds** to load.

The one-time costs for the two alternatives are either:

- **High-speed internet: €1.50**
- **Low-speed internet: €0.50**

or

- **High-speed internet: €4.50**
- **Low-speed internet: €3.50**

At the beginning of the experiment you will learn which of the two price levels will apply in the experiment. You will receive a decision sheet where you have to indicate your choice for one of the two internet alternatives. After you have made your decision, your computer is set up according to your choice and you can use the internet for the next 45 minutes. After 45 minutes you will receive your payment (15 Euro minus the cost for the chosen internet access) and the experiment is finished.

Figure A5.2: Information email for the participants of treatment UHP.

Information on the experiment

Welcome to this experimental study. Please do not talk to other participants from now on. You are not allowed to use your own paper, mobile phones or any other printed media or electronic devices.

For the duration of the experiment (45 minutes) you have to purchase **high-speed or low-speed internet** which you can use at your convenience during the experiment - please note that it is not possible to buy no internet access at all! For participating in the experiment you will receive a fixed payment of **12 Euro** minus the costs for the selected internet alternative.

You can use the internet at your convenience during the experiment and there are no other tasks to complete. Note that we do not store any information: the browser will reset automatically after the experiment! Neither the experimenters nor any third party can track which websites you have visited.

High-speed internet (regular internet access via the HHU-network) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average less than 5 seconds** to load.

Low-speed internet (restricted internet access) can be described as follows:

- Frequently visited pages like facebook.de, spiegel.de or bild.de take **on average about 30 seconds** to load.

After all participants read the instructions, you will receive a decision sheet where you have to indicate your choice for one of the two alternatives.

The one-time costs for the two alternatives are:

- **High-speed internet: 1.50€**
- **Low-speed internet: 0.50€**

After you have made your decision you can use the internet for the next 45 minutes. [Restrictions: you are not allowed to use the speakers of the computer in order to not disturb other participants, to visit illegal websites or to perform any downloads].

After 45 minutes you will receive your payment (12 Euro minus the cost for the chosen internet access) and the experiment ends.

If you have any questions, please do not hesitate to contact the experimenters at any time. Just raise your hand and we will answer your question privately.

After completing the experiment, please wait at your seat until you are called.

Figure A5.3: Instructions for the participants of treatment LP.

Appendix B: Subject characteristics

Table B5.1: Subject characteristics across treatments

Treatment	**Variable**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
LP	Gender	0.456	0.503	0	1	57
	Age	24.925	3.807	18	38	53
	Undergraduate (Bachelor)	0.660	0.478	0	1	53
	Humanities	0.345	0.48	0	1	55
	Human medicine	0.073	0.262	0	1	55
	Law	0.036	0.189	0	1	55
	Mathematics and Natural Sciences	0.273	0.449	0	1	55
	Economics	0.273	0.449	0	1	55
	Electrical Engineering	0	0	0	0	55
HP	Gender	0.492	0.504	0	1	59
	Age	24.833	3.575	20	38	54
	Undergraduate (Bachelor)	0.596	0.496	0	1	47
	Humanities	0.333	0.476	0	1	57
	Human medicine	0.123	0.331	0	1	57
	Law	0.088	0.285	0	1	57
	Mathematics and Natural Sciences	0.193	0.398	0	1	57
	Economics	0.246	0.434	0	1	57
	Electrical Engineering	0.018	0.132	0	1	57
UHP	Gender	0.509	0.505	0	1	53
	Age	24.234	3.198	18	32	47
	Undergraduate (Bachelor)	0.558	0.502	0	1	52
	Humanities	0.25	0.437	0	1	52
	Human medicine	0.096	0.298	0	1	52
	Law	0.038	0.194	0	1	52
	Mathematics and Natural Sciences	0.308	0.466	0	1	52
	Economics	0.308	0.466	0	1	52
	Electrical Engineering	0	0	0	0	52
Full sample	Gender	0.485	0.501	0	1	169
	Age	24.681	3.538	18	38	154
	Undergraduate (Bachelor)	0.605	0.490	0	1	152
	Humanities	0.311	0.464	0	1	164
	Human medicine	0.098	0.298	0	1	164
	Law	0.055	0.228	0	1	164
	Mathematics and Natural Sciences	0.256	0.438	0	1	164
	Economics	0.274	0.448	0	1	164
	Electrical Engineering	0.006	0.078	0	1	164

Appendix C: Formal analysis of Kőszegi and Rabin (2006)

In order to investigate whether Kőszegi and Rabin (2006) can account for Result 2, we determine all personal equilibria (PE) in treatment UHP. Suppose that an agent expects to find the low price level with some exogenous probability $0 < p_L \leq 1$ and a high price level with $p_H := 1 - p_L$. Given the low price level, the decision maker expects to choose the low-quality option with probability p_s^L and the high quality option with probability $1 - p_s^L$. Given the high price level, she expects to opt for the low-quality option with probability p_s^H and for the high-quality option with probability $1 - p_s^H$. Then, the reference price level r_p equals $r_p(p_L) := p_L\ (0.50\ p_s^L + 1.50\ (1 - p_s^L)) + (1 - p_L)\ (3.50\ p_s^H + 4.50\ (1 - p_s^H))$ and the reference quality level is given by $r_q(p_L) = q_L\left(p_L\ p_s^L + (1 - p_L)\ p_s^H\right) + q_H\left(p_L\ (1 - p_s^L) + (1 - p_L)\ (1 - p_s^H)\right)$.

A PE requires the following consistency criterion to be satisfied. Given the reference point (r_p, r_q), the decision maker finds it optimal to follow her plan at the second stage, that is, if prices are low (high) she chooses the low-quality option with probability p_s^L (p_s^H, respectively).

According to KR, the utility derived from an alternative $k = (p_k, q_k)$, given a reference point $r = (r_p, r_q)$, is given by

$$u(k|r) = v(k) + n(k|r),$$

where $n(k|r)$ denotes the gain-loss utility relative to the reference point (which is zero in a rational model). As before, the agent's consumption utility $v(k)$ is linear and equals $v(k) = q - p$. Suppose that the high- and the low-quality product lie on a rational indifference curve, thus $q_H = q_L + 1$. We assume that n is additively separable across dimensions, i.e., $n((p_k, q_k)|r) := n_p(p_k|r_p) + n_q(q_k|r_q)$, and $n_i(x|y) := \mu(v_i(x) - v_i(y))$ for a function μ which satisfies the properties of the value function introduced in Kahneman and Tversky (1979). In particular, let μ be a piecewise linear function which is defined by $\mu(x) = \eta x$ if $x > 0$ and $\mu(x) = \eta\lambda x$ if $x \leq 0$, where parameter $\eta > 0$ is a measure of the weight a decision maker assigns to the gain-loss utility and λ is a coefficient of loss aversion. Following prospect theory, losses relative to the reference point receive larger weights than gains, i.e., $\lambda > 1$. As choosing the high quality will never represent a loss in the quality dimension we have

$$n_q(q_H|r_q) = \eta\ (q_H - r_q).$$

Analogously, the low quality will never represent a gain, that is

$$n_q(q_L|r_q) = \lambda\eta(q_L - r_q).$$

Concerning prices, the low quality product's price will never represent a loss at the low price level and the high quality product's price will never represent a gain at the high price level.

In the following we discuss the case where subjects expect both scenarios with equal probability, that is, $p_L = 50\%$. We then show that the only PE involves choosing the low-quality product with probability 1.[19]

First, if there is a solution with $0 < p_s^H < 1$, then the decision maker is indifferent between opting for the high and the low quality at the second stage at high prices, that is,

$$\begin{aligned} &q_L - 3.50 - n_p(3.50|r_p(p_L)) - \lambda\eta(r_q(p_L) - q_L) \\ =&q_H - 4.50 - \lambda\eta(4.50 - r_p(p_L)) + \eta(q_H - r_q(p_L)) \end{aligned}$$

[19]Straightforward computations show that this pure strategy equilibrium exists also for arbitrary expectations of p_L. If p_L becomes sufficiently small such that the low quality option at the high price level can be perceived as a gain in the monetary dimension for some p_s^H and p_s^L, then, however, multiple equilibria exist. In that case, it is also an equilibrium to have $p_s^H = 0$ and in addition there exists also a strictly mixed equilibrium such that any choice pattern can be in line with KR.

or, with our specification,

$$\begin{aligned}&q_L - 3.5 - \eta\lambda(3.5 - r_p(0.5)) - \lambda\eta(r_q(0.5) - q_L)\\=&q_H - 4.5 - \eta\lambda(4.5 - r_p(0.5)) + \eta(q_H - r_q(0.5)).\end{aligned}$$

As $q_H = q_L + 1$, this is equivalent to $r_q = q_H$, which is a contradiction as we assumed $p_s^H > 0$. Thus, it must hold that $p_s^H \in \{0, 1\}$.

Second, suppose $p_s^H = 1$. Then, it has to be (weakly) optimal to choose the high quality at the second stage, that is

$$q_L - 3.50 - \eta\lambda(3.50 - r_p) - \eta\lambda(r_q - q_L) \leq q_H - 4.50 - \eta\lambda(4.50 - r_p) + \eta(q_H - r_q)$$

or, equivalently,

$$\lambda(q_H - r_q) \leq q_H - r_q,$$

which is a contradiction as $\lambda > 1$ and $q_H > r_q$.

Third, suppose $p_s^H = 0$ such that

$$q_L - 3.50 - \eta\lambda(3.50 - r_p) - \eta\lambda(q_L - r_q) \geq q_H - 4.50 - \eta\lambda(4.50 - r_p) + \eta(q_H - r_q)$$

has to be fulfilled. Indeed, the equivalent condition

$$\lambda(r_q + 1 - q_L) > (q_H - r_q),$$

is satisfied as the reference quality is closer to q_L than to q_H and in particular $r_q + 1 - q_L > q_H - q_L$ and $q_H - r_q < q_H - q_L$. Thus, in a personal equilibrium the decision maker will rationally expect to choose the low quality in order to minimize her loss in the price-domain.

Eidesstattliche Erklärung

Ich versichere an Eides statt, dass die vorliegende Dissertation von mir selbstständig und ohne unzulässige fremde Hilfe unter Beachtung der „Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich–Heine–Universität Düsseldorf" erstellt worden ist. Die Arbeit wurde bisher in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

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