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The price of broadband quality: tracking the changing valuation of service characteristics

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Abstract

This paper investigates how retail broadband prices, choice and quality are changing over time. Using a dataset containing daily observations of plans offered in Ireland from 2007 to 2013, this paper applies hedonic modelling techniques to observe the changing pricing of service characteristics. Although we find that average nominal prices remain static throughout our sample period, quality of service has risen dramatically over time, particularly with respect to download speed. Some characteristics of broadband plans exhibit broadly stable valuations over time, but the elasticity of price with respect to advertised download speed and the premium on bundled services declined for most types of broadband plans during the sample period. In addition, the retail price premium enjoyed by the incumbent operator fell significantly since 2007.

Key words: broadband services, market analysis, hedonic model, Ireland

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1. Introduction

Broadband availability, price and quality have become competitive variables at national and supranational level, as jurisdictions seek to improve their endowment of network infrastructures and services seen as essential for competitiveness and social inclusion.

Design of policies aimed at both retail and infrastructure markets can benefit from information on how retail broadband services are priced and how price, quality and choice of services are changing over time. For example, public interventions to make higher speed broadband available in geographical areas not covered by commercial offerings often involves a subsidy to close the gap between revenue available from local supply and the cost of provision. If providers of these services can earn additional revenue from offering higher download speed in newly-served areas, this would help reduce the required subsidy (even if the increase were not enough to eliminate the need for a subsidy entirely). On the other hand, if no premium for higher speed is sustainable, the subsidy will have to be higher.

Most existing studies of how broadband quality attributes are priced or valued take the pricing of these characteristics to be static. However, given the rapid pace of innovation in broadband access services and the applications that rely on them, as well as the substantial increase in adoption rates since broadband was introduced, there is no reason to think the prices of increments to these attributes should be stable over time.

In many jurisdictions a promising source of such information has emerged in tandem with rising competition and retail deregulation: price comparison websites. In this paper, we estimate hedonic regressions using seven years (2007 to 2013) of data from a price comparison website in Ireland, treating the price of a broadband plan as a function of its qualitative characteristics. In contrast to most previous hedonic modelling research on broadband markets, we have a long enough span of time in the dataset to see changes in the valuation of characteristics as the market evolves.

We find that the elasticity of price with respect to download speed fell during the sample period, most significantly for smaller operators, those not using cable technology and in the earlier part of the period. By the end of the sample period the elasticity is very low. Another important finding is that the fixed line incumbent's retail price premium has fallen significantly since 2007.

In common with other researchers, we find that plans with limits on data transfer have lower prices, but we do not find a statistically significant price effect from contracts. Higher upload speed attracts a price premium in some sub-samples. Bundled services also show a price premium in plans based on digital subscriber line (DSL) technology, but it has been declining over time. The discount on fibre to the home services seen in other jurisdictions developed over time in Ireland and is only statistically significant when small operators are included. When TV service is included in bundles, it adds a significant premium as seen elsewhere.

The paper is structured as follows: Section 2 details previous literature which provides context to this research. Section 3 details the methodology and data used in our analysis. Section 4 presents empirical results and Section 5 offers some conclusions.

2. Background and previous research

Most research in this area takes marginal effects of characteristics on price to be static over time. Two studies based on large international datasets have been published recently. Wallsten and Riso estimate a linear hedonic model on over 25,000 broadband prices drawn from all OECD countries from 2007 to 2009 (Wallsten and Riso 2015). They find that broadband speed has a positive marginal effect that declines with speed level (modelled as a quadratic relationship). Data transfer limits, contracts and provision of service through a fibre connection have significant negative associations with service prices, while bundles attract premium prices. Calzada and Martínez-Santos (2014) use panel data on a subset of plans in 15 EU countries from 2008 to 2011. They observe a positive relationship between download speed and price (with an elasticity of around 1.3) and they find that services provided by cable modem and fibre are cheaper than those delivered through DSL. Prices are higher when broadband services are bundled with telephony (by about 10%) and television (36%). The study also exploits cross-country variation in market structure and regulatory arrangements to examine the effects of access regulation on prices.

Crocioni and Correa (2012) suggest that estimating the extent of pricing power in the residential broadband market with a hedonic model could be useful in assessing the effectiveness of competition. Pricing power, the extent to which a supplier can maintain prices above those of competitors for equivalent services, is difficult to assess in differentiated goods markets such as telecoms. In principle, hedonic models allow the pricing behaviour of providers of differentiated products to be compared on a like-for-like basis by controlling for differences in service characteristics.

Their research uses cross sectional data for Ireland and the Netherlands for 2007, a year in which neither country's incumbent firm was tightly regulated. For Ireland, the authors found that the market incumbent for DSL (Eir, then known as Eircom) had substantial pricing power.

Some research has allowed for temporal change in selected coefficients. Lyons and Savage (2013) estimate a linear hedonic model on data from the Irish residential broadband market, 2006-2011, and include an interaction between download speed and time. They find a negative and significant relationship. Greenstein and McDevitt (2011) evaluate the quality-adjusted change in prices of broadband packages in the United States from 2004 to 2009 through a mixture of matched-model methods and hedonic modelling. The main result in the paper is that there was relatively little reduction in quality-adjusted broadband prices over time compared to other innovative technologies such as PCs. This is surprising, because one would expect that the technologies underlying broadband supply were subject to similar patterns of cost reduction to those affecting other information and communications technology (ICT) sectors, driven by rapid technological innovation.

As a by-product of this analysis, Greenstein and McDevitt show changes in several coefficients when the model was run separately on sub-samples from 2004-6 and 2007-9. Of particular relevance to our analysis, the positive and significant effect of logged DSL download speed on prices observed in the earlier sub-sample was not reflected in the later one, although the speed coefficient for cable services was broadly stable over time. This offers some evidence that the price premium on additional download speed changed as basic broadband services matured but also suggests that the change may have varied by technology or type of operator.

3. Methods and data

This section describes the dataset used for this research and the model we apply.

3.1 Methodology

A hedonic price function treats the price of a good as the sum of the implicit prices of the features of that good. Based largely on the research of Griliches (1961) and Rosen (1974), the idea was to construct a proxy indicator for the value of manufactured products incorporating both quantity and quality. For this research we model the price of a broadband plan as the sum of the values of its characteristics (download and upload speed, contention, access type and operator etc). The basic hedonic regression model is outlined as follows for plan *i* on day *t*:

$$
\begin{aligned}
ln(Monthly\ Price)_{it} \\
&= ln(Download\ Speed)_{it} + ln(Upload\ Speed)_{it} + ContentionRatio_{it} \\
&+ TransferLimited\ _{it} + \ TransferLimit_{it}\ + BundledPlan_{it} \\
&+ Contract_{it}\ + MinimumContract_{it} + \mathbf{AccessType}_{it} \\
&+ \mathbf{OperatorGroup}_{it}\ + PreTVSample_{it} + TVIncluded_{it} + Quarter_{it} \\
&+ \varepsilon_{it}
\end{aligned}
$$

In an innovative market such as that for broadband services, the value of a given characteristic may change over time. For example, Stengos and Zacharias (2006) show that many characteristics of personal computers have a time-varying effect on prices. To allow for this, we first estimate the model with linear time interactions added for all the explanatory variables where it is possible to do so. This allows the slope coefficient for each characteristic to change over the sample period. We then test this model down by omitting variables and time interactions that are collectively insignificant. The resulting parsimonious model contains a mixture of fixed and time-varying coefficients, as dictated by the data.

We explore whether the time profiles for some key coefficients are non-linear, with a particular focus on download speed and the price premium on plans offered by the historical incumbent operator. Another variant we estimate limits the dataset to operators with more than 10% market share, which allows for the possibility that firms in the competitive fringe behave differently from larger suppliers. Robustness checks include variants of the model without time interaction terms, removing the log transformation of the download and upload speed variables and separate estimation on plans with specific access types (DSL, cable and other).

The next section discusses the data used in our models and the expected relationships between characteristics and the price of broadband service.

3.2 Data description

The broadband market in Ireland grew rapidly from 2001 to 2010, when it reached a plateau at about 85% penetration (see Figure 1). With access based mainly on DSL and cable technologies, there are also substantial numbers of connections using datacard access via cellular networks and fixed wireless links. Higher speed services via fibre to the cabinet and to the home are now being introduced, but such innovations fall mainly outside our sample period.

Figure 1. Residential broadband penetration rate in Ireland (subscriptions/number of households; includes datacard users)

The main dataset for this paper is drawn from Callcosts.ie, a price comparison website maintained by Ireland's Commission for Communications Regulation (ComReg). Callcosts helps residential consumers compare the cost of mobile, home phone and broadband plans. Operators are encouraged (but not required) to list their plans on Callcosts. ComReg (2014) believes the vast majority of plans are accounted for, but some variation in promptness or completeness of updating cannot be ruled out. The dataset contains information on the price and qualitative features of each plan.

Although the data available ranges from 2006 to the present, coverage was limited at the start so we use data from 2007. Our final (full sample) dataset contains 525,141 plan-day observations from 2007 to 2013 covering standalone and bundled plans from Cable, DSL, Fibre, Fixed wireless and Datacard technologies[1]. This section details the key variables used in our analysis.

Price

The dependent variable in our models is the natural log of the monthly price of a broadband plan. It includes the monthly price in addition to once-off payments (such as connection or modem fees) amortised over the length of the contract. For packages with no specified contract duration we spread any initial cost over a twelve month period. This helps to ensure that plan prices are comparable, although it may overstate the true cost of one-off fees for customers who stay with the same plan for longer than the minimum period (and vice versa).

Download and Upload Speed

The Callcosts dataset lists the advertised download and upload speeds for each plan (in Mbit/s). We apply a log transformation to these variables, so their coefficients can be interpreted as elasticities. There is no theoretical basis for specifying this particular relationship between speed and price, but the approach we use here is in line with previous literature (e.g. Deligiorgi *et al.* [2007], who test a range of functional forms) and substantially improves the model fit in comparison to linear or semi-log models.

Access Type

For modelling purposes we group the technologies used to supply broadband service into five access type categories (ADSL/VDSL, Cable, FTTH/Fibrelan, Datacard, Fixed wireless). The annual shares of plans using each access type is shown in Table 1 below. ADSL is the most prevalent access type in the sample. Satellite-based services are omitted from the analysis because their prices are more than six times higher on average than other services and there are so few satellite connections in Ireland that their market share is not reported separately in regulatory statistics. Other technologies have varying geographical availability, with cable and fibre largely restricted to urban areas. Unfortunately our dataset lacks geographical detail. Because cost structures, geographical availability and unobserved quality attributes vary by technology, we expect that access type may have a

[1] Our research does not cover the data usage of mobile phones, as Datacard only covers mobile broadband typically provided through a 'dongle' or 'mobile hotspot'.

significant association with price. Since the dependent variables in our regressions are in logs, the access type coefficients represent the percentage premium in price each access type commands over the reference category (DSL).

Table 1: Frequency of plans by access type

	Proportion of full sample (%) (525,141 plan-days)						
Access Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Cable	9.74	7.7	8.02	8.59	9.74	7.7	8.02
Datacard	1.98	4.18	5.42	6.74	1.98	4.18	5.42
DSL	60	64.3	64.9	59.7	60	64.3	64.9
Fibrelan or FTTH	0.01	0.01	0.01	1.77	0.01	0.01	0.01
Wireless	28.3	23.8	21.7	23.2	28.3	23.8	21.7

Source: Analysis of Callcosts.ie data

Contention Ratio

Callcosts.ie records the reciprocal of the advertised contention ratio (potential/actual bandwidth), e.g. it takes the value 24 for a 1:24 contention ratio. Measured this way, lower contention should be associated with a better user experience, all other things equal. We anticipate a negative relationship between prices and contention, with customers paying more for uncontended lines.[2]

Operator Group

The final dataset contains 37 operators, we which group into nine categories for inclusion in the regressions: Eir (then called Eircom), UPC, Vodafone, Imagine, Digiweb, Meteor/eMobile (owned by Eir), O2, Three and Other Authorised Operators. Eir is the historical incumbent retail broadband provider in Ireland. In line with EU policy, Ireland's regulator ComReg does not apply economic regulation to Eir's broadband services at the retail level. However, ComReg has deemed Eir to have significant market power (SMP) at the wholesale level and applies a set of regulatory measures (ComReg 2010).

[2] Contention is not reported for datacard plans in the Callcosts database, so we set their contention rate to the mean of the wireless category (27.6).

We include a dummy variable for each operator group in our models to take account of operator-specific quality or brand effects. We also run a separate model with a dummy variable identifying the incumbent operator's price premium over the average for other operators, with a view to updating the analysis of pricing power set out in Crocioni and Correa (2012).

Operator market shares

Similar to Greenstein and McDevitt (2011), our data does not contain actual subscription numbers for each plan. However, we do have quarterly market share data for each operator from 2010 to 2013. These are drawn from ComReg's *Quarterly Key Data Report,* which details developments in the communications sector and includes data on telephony and broadband markets.[3] Average annual market shares based on these data are shown in Table 2 below.

Table 2: Average annual broadband market share by operator

	Average annual operator market shares (%)			
Operator	**2010**	**2011**	**2012**	**2013**
Eir	32.4	29.6	28.4	27.7
UPC	11.7	14.5	17.8	20.1
Vodafone	20.2	20.7	21.1	20.2
Imagine	3.59	3.21	2.65	2.45
Digiweb	2.00	1.66	1.68	1.63
Meteor/eMobile	2.95	3.81	3.75	3.13
O2	9.91	10.0	9.13	7.90
Three	12.2	11.9	10.9	9.66
Others	4.98	4.66	4.75	7.26

Source: Analysis of ComReg Quarterly Key Data Reports

We use these shares to estimate an alternative model including only operators that had a market share over 10% in 2011 Q1, for comparison with the basic specification in which all plans are given equal weight.

[3] ComReg's *Quarterly Key Data Reports* cover 95% of the operators in the Irish residential broadband market (ComReg 2014).

Bundled plans

Of the 2,344 unique plans in our dataset, 1,481 are bundles and 863 are stand-alone broadband offerings. For the purposes of this research, bundled plans can be any combination of TV, phone and broadband services. Higher prices for bundled plans could arise if there is extra cost and perceived value for the additional features and better integration offered in bundles, or the segments of the market served by bundles might exhibit less consumer switching as shown for UK communications services by Burnett (2014), leading to higher retail margins.

Presence and level of transfer limits

Some plans impose a limit on download capacity, which we refer to as a transfer limit. Transfer Limited is a binary variable (1=Limited, 0=Unlimited) to distinguish these plans and Transfer Limit (Gb) is a continuous variable measuring the size of the download allowance on plans which are limited. 69% of the observations in the dataset are limited, with 31% of observations being unlimited plans. Imposition of a transfer limit will tend to deter heavy data users from selecting the plan or may indicate that the actual price they pay will be higher (i.e. if there are additional charges for use beyond the limit). *Ceteris paribus*, transfer-limited plans should be (weakly) less costly to supply. Also, plans with no transfer limit or a high limit will be offer additional value to high users, who should be willing to pay extra for it. Taking these effects together, we expect the Transfer Limited dummy variable to have a negative association with price and the Transfer Limit variable to have positive association.

Presence of a contract and length of minimum contract period

The vast majority of plans in the sample require a contract, the main exception being certain datacard plans. The binary contract variable (1=Contract, 0=No Contract) aims to differentiate between pay-as-you-go plans and those with a specified duration. The minimum contract length variable measures contract duration in months) for plans with a contact, and it ranges from 6 to 18 months in this dataset. The presence of a contract should have a (weakly) negative association with price since it limits the customer's freedom of action, and longer contracts should have lower prices.

TV included and pre-TV sample

Callcosts began accounting for plans with a bundled TV service from the start of 2013. The binary TV included variable (1=TV included, 0=No TV) reports this. Conversely, the Pre TV Sample variable is equal to one if the observation appeared from 2013 onwards and zero if the observation appeared at any point before 2013. Both of these variables are included in the analysis to account for any rise in prices that may be associated with the recent trend of bundling a TV package with internet and telephony.

Table 3 provides summary statistics for each of the continuous variables used in our empirical analysis.

Table 3: Descriptive statistics

	Full sample (525,141 plan-days)			
Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
Monthly Price (€)	52.0	18.8	10.4	185
Download speed Mbit/s	9.19	17.3	0.5	200
Upload speed Mbit/s	1.07	2.11	0.0625	20
Contention Ratio (reciprocal)	26.7	18.7	1	48
Transfer Limited [1/0]	0.692	0.462	0	1
Transfer Limit (Gb)	48.2	105	0	500
Bundled [1/0]	0.439	0.496	0	1
Contract [1/0]	0.989	0.105	0	1
Min. contract length (Months)	11.4	2.37	0	18
Pre TV sample [1/0], up to 2013	0.137	0.343	0	1
TV included [1/0], 2013 only	0.00433	0.0657	0	1

Figure 2 displays the number of plans available over time according to Callcosts. The number of plans offered rose sharply from 2008 until 2011, after which the number of plans began to fall during 2012. Since then, the number of plans has stabilised around 250.

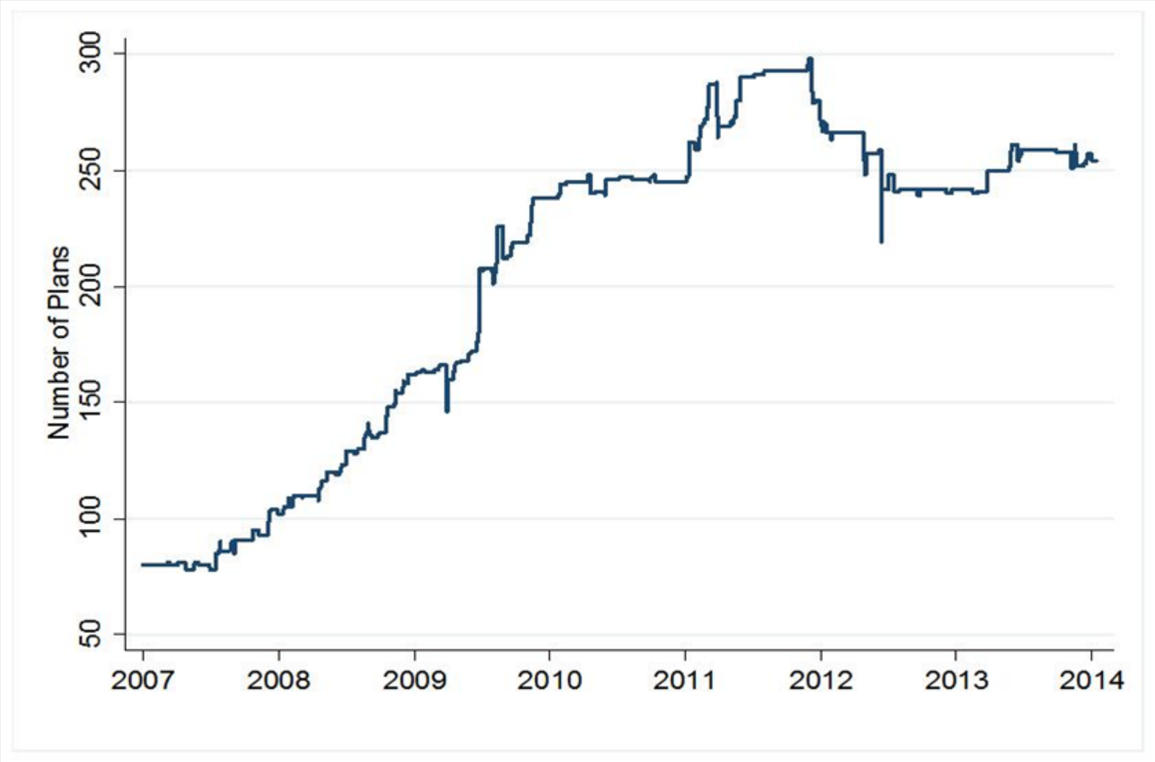

Figure 2. Number of broadband plans offered over time

The average nominal price of broadband services in Ireland has been remarkably stable over time. Figure 3 displays the median monthly price of broadband plans, including and excluding an allowance for annualised one-off costs. Maintaining a level of €45- €50 per month, broadband plans were falling in price in real terms, particularly if one considers the rapid improvement in service quality over the period.

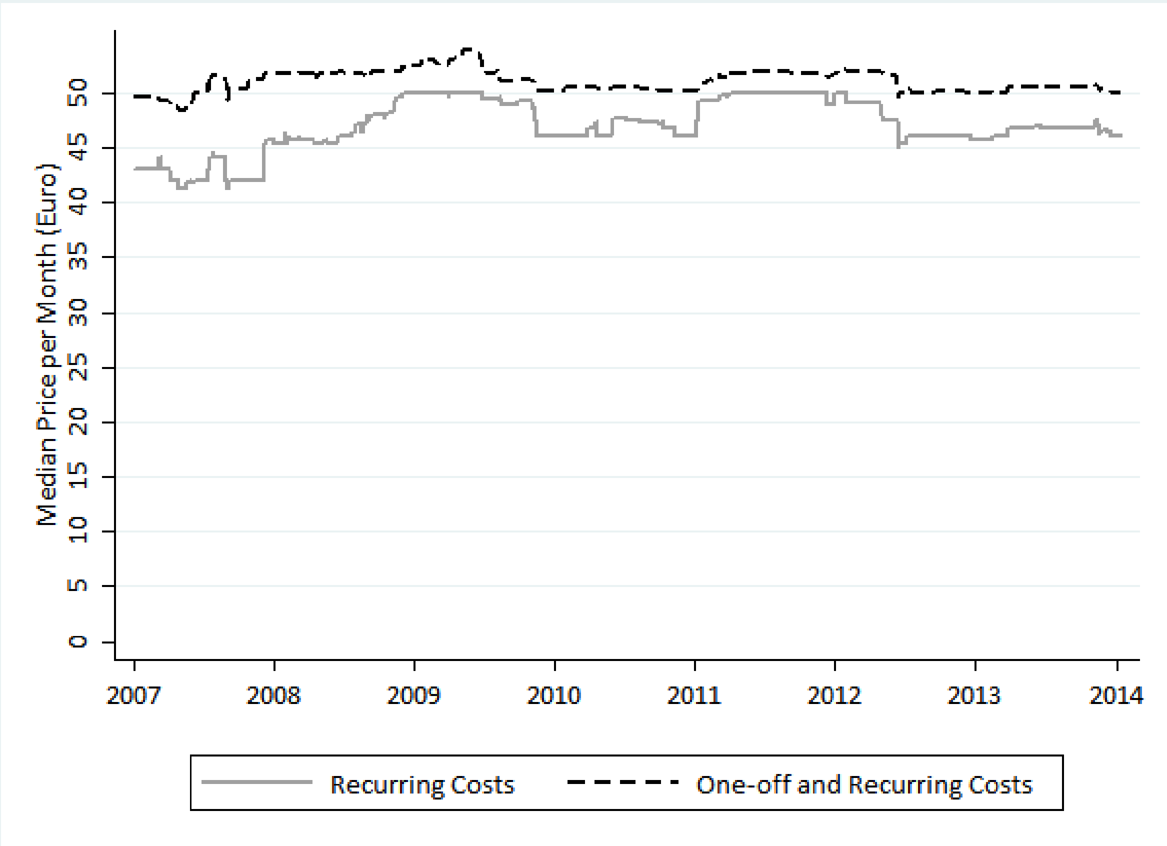

Figure 3. Median price per month of broadband services in Ireland, with and without annualised one-off costs

The average download speed offered by broadband plans has increased considerably over time, as shown in Figure 4 below. While the median speed has risen considerably, the mean has risen more – especially in recent years.

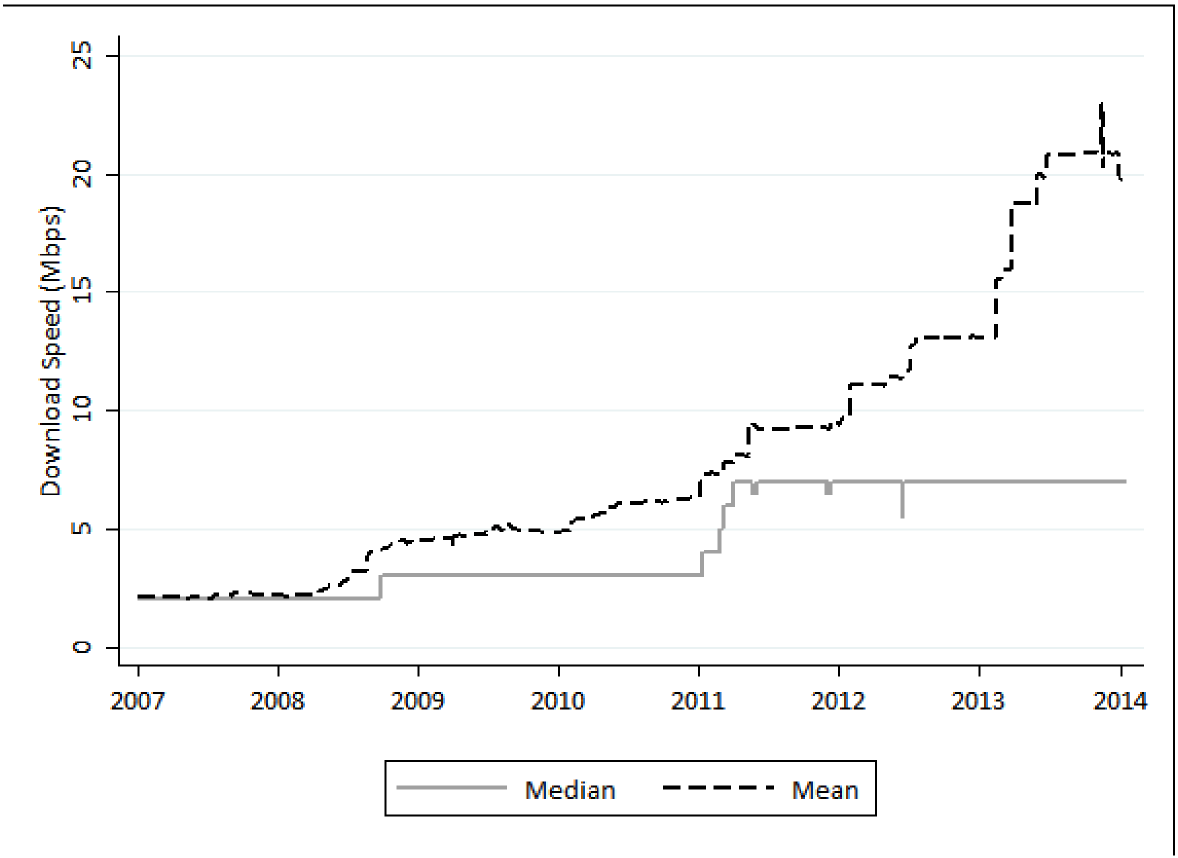

Figure 4. Average download speed of broadband services in Ireland, mean and median

The fast-growing wedge between mean and median speeds is driven by the presence of a small number of plans offering very high speeds, typically available only in urban areas.

Increases in median download speeds have been characterised by stable periods punctuated by jumps, which are likely driven by changes in the underlying technology; for example, the mean download speed experienced an upward shift from ~6Mbps to ~10Mbps during 2011. This occurred during a period where the number of plans available fell from its highest value to a stable level of ~250 plans (as shown in Figure 2). Technology upgrades seem to have induced or coincided with market changes, whereby operators revamped their product offerings with a significantly improved product offered at broadly similar prices. For example, in 2010, Eir upgraded customers in some areas on a 1Mb, 3Mb or 7Mb plan to an 8Mb plan (Eircom 2010).

3.3 Some caveats

The main weakness of our dataset is the absence of information on the number of subscriptions for each plan. If subscriptions data were available, it would be possible to construct a structural market model and one would be more confident in assessing causality of relationships.

A second important omission is temporary promotions. Some promotional activity is listed on Callcosts.ie, but historical promotions are not stored systematically. As a result we are not able to take price promotions into account. Promotions are important in the market, because many subscriptions arise from doorstep or telephone sales of plans with substantial introductory discounts.

Another problem with our data (in common with most of the existing literature) is that our dataset lists advertised, not actual, download and upload speeds. These do not necessarily reflect the actual speeds customers receive. Unfortunately, no data are available on actual data transmission speeds supplied.

Finally, although county-level availability information is stored in the Callcosts database, historical spatial information is not retained and we have access to such data for only two time points. As a result, our analysis is carried out at national level.

4. Results

In this section we report hedonic regression results for the model set out in sub-section 3.1, exploring the implications and robustness of the model by making changes to the variables included, the transformations applied to some variables and the data set on which it is estimated.

4.1 Regression results – full sample

The regressions shown in Table 4 allow for time varying effects in most broadband plan attributes. We first test for evidence of linear variation in coefficients over time, with Model 1 showing results for each attribute's level and interaction with a time trend (in quarters).

Table 4: OLS hedonic regression results for 2007 to 2013; plan-day data with linear time interactions						
Variables and statistics	**Model 1: All variables**		**Model 2: Parsimonious version**		**Model 3: No time interaction terms, other variables from Model 2**	
Dep. variable	Ln(Monthly price of plan)		Ln(Monthly price of plan)		Ln(Monthly price of plan)	
	Coef.	**Robust SE**	**Coef.**	**Robust SE**	**Coef.**	**Robust SE**
lnDownload speed	0.149	0.0296***	0.139	0.0232***	0.0688	0.0156***
lnDownload speed*Time	-0.00430	0.00150***	-0.00352	0.000912***		
lnUpload speed	0.0634	0.0389	0.0945	0.0245***	0.0904	0.0226***
lnUpload speed*Time	0.00196	0.00175				
Contention ratio	-0.000685	0.00160	0.00165	0.000793**	0.00135	0.000777*
Contention ratio*Time	0.000131	6.99e-05*				
Access type						
Cable	0.137	0.0872	0.0654	0.0799	-0.0475	0.0676
Datacard	-0.605	0.146***	-0.538	0.148***	-0.931	0.0643***
DSL	REF		REF		REF	
FTTH or fibrelan	0.0727	0.152	0.0503	0.140	-0.352	0.0686***
Fixed wireless	-0.0493	0.0584	-0.0708	0.0624	-0.0404	0.0429
Access type*Time						
Cable*Time	-0.0104	0.00431**	-0.00562	0.00367		
Datacard*Time	-0.0208	0.00844**	-0.0243	0.00871***		
DSL*Time	REF		REF			
FTTH or fibrelan*Time	-0.0174	0.00829**	-0.0152	0.00692**		
Fixed wireless*Time	0.000340	0.00279	0.00206	0.00268		
Transfer limited? [yes=1]	0.00144	0.0661	-0.0789	0.0376**	-0.0865	0.0357**
Transfer limited*Time	-0.00496	0.00273*				
Transfer limit	-0.000237	0.000405				
Transfer limit*Time	1.26e-05	1.54e-05				
Bundled plan? [yes=1]	0.0842	0.0342**	0.0935	0.0328***	0.0370	0.0210*
Bundled plan*Time	-0.00326	0.00183*	-0.00375	0.00179**		
Contract? [yes=1]	-0.250	0.231				
Contract*Time	0.00736	0.0137				
Min. contract period	0.00910	0.00797				
Min. Contract period*Time	-0.000348	0.000502				
Pre-TVsample? [yes=1]	0.0226	0.0110**	0.0205	0.0104**	-0.00988	0.0106
TV included? [yes=1]	0.394	0.0492***	0.407	0.0422***	0.391	0.0506***
Quarterly time trend	-0.00920	0.0137	-0.00675	0.00356*	-0.00593	0.00105***
Constant	4.359	0.270***	4.213	0.123***	4.196	0.0701***
Operators FE	YES		YES		YES	
Operators FE*Time	YES		YES		NO	
Observations	525,141		525,141		525,141	
Plans	2,344		2,344		2,344	
Adjusted R-squared	0.571		0.568		0.544	
*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively; standard errors allow for clustering at plan level.*						

Download speed is probably the most prominently-advertised characteristic of a plan apart from the identity of the operator supplying it, and a higher speed allows a wider range of applications to be used, so we expect a significant positive association with the price. The elasticity of price with respect to download speed is low, but positive and highly significant. It has also fallen significantly over the sample period, confirming the pattern identified in Lyons and Savage (2013). In the next sub-section we examine the time pattern of the download speed elasticity in more detail.

The bundled plan dummy variable shows a similar pattern of effects, with a premium of about 8% at the start of the sample period but a significant decline over time. Inclusion of TV service within the bundle involves a substantial premium on the price (about 40%), as expected. Because this indicator variable was only added to the dataset in its final year, we could not test how this is changing over time.

Among the access type variables, only datacard has a significantly different price from the reference category of DSL. Datacard services are much less expensive than other access types and this discount grew significantly over the sample period. The FTTH or fibrelan dummy variable is not significantly different from DSL at the start, but a discount for these plans opens up over time. It may be that as such services became available in more localities during the middle to later part of the sample they were priced a discount to DSL to encourage take-up. Operator fixed effects were also significant in the model, and later in this section we explore how the premium charged by the historical incumbent operator changed over the sample period.

The quarterly time trend is not significant; we earlier noted how stable average nominal prices have been over time. However, several other attributes we expected to affect the user experience show no significant association with price when time interactions are included. Upload speed, contention ratio, whether transfer capacity is limited, the presence of a contract or duration of the minimum contract period are all at best marginally significant in this model.

In some of these cases, the lack of significance is probably due to multicollinearity. Model 2, also in Table 4, is tested down to exclude variables that are collectively insignificant: F(9,2343)=1.29, p-value=0.238.

In the parsimonious model, upload speed exhibits a low positive elasticity that does not vary significantly over time. Surprisingly, the contention ratio also shows a positive effect, which given the way this variable is constructed implies that prices are higher when a plan offers more contended service. However, the estimated elasticity is very low and is not robust to changes in the set of variables or the sample, so it may be a spurious result.

The presence of transfer limits confers a statistically significant constant price discount of about 8% in this model. This is in line with expectations, because such limits should tend to reduce the cost of providing service by constraining or deterring users that make particularly heavy use of capacity. We were unable to detect an effect from the stringency of the transfer limit. Other effects are largely unchanged from the results shown in Model 1.

To illustrate how different our results would look had we not taken time variations in some coefficients into account, Model 3 shows the basic model without time interactions. The estimated download speed elasticity is positive, at about 0.07, which stands in contrast to the pattern of a higher elasticity falling significantly during the sample period. In contrast, upload speed has similar positive coefficients in Models 2 and 3; we had earlier noted that the time interaction was not significant here. It seems that upload speed had a stable positive elasticity during this period. By omitting time interactions we would miss the deepening discounts on datacard and FTTH connections and the falling premium on bundled plans.

Another test of robustness is shown in Table A1 in the annex. Here we estimate the model with download and upload speed measured in MB/s levels rather than log transformed, and we add a squared download speed term. The pattern of results is similar to the models reported above, but download speed shows a positive marginal effect on prices that declines as speed rises. This is similar to the result reported in Lyons and Savage (2013). Since the R^2 value is lower than in the models where speed variables are logged, we prefer the latter.

4.2 Taking market share into account

Ideally we would like to know the quantities of each plan that were purchased rather than just the price. It is likely that some plans were much more popular than others, and treating each plan-day observation as equally important may give too much weight to the characteristics of plans that attracted little demand. We do not have access to demand data at plan level, but quarterly market shares are available at operator level from 2010-2013. To take market shares into account in a simple way, we re-run Model 2 over the full sample period but with a sample restricted only to large operators (those achieving >10% market share in 2011 Q1), thus eliminating plans of operators that had few subscribers but weighting plans of large operators equally.

Model 4 in Table 5 shows the results. The download elasticity is unchanged, but the time interaction with it is not significant. We look more closely at the time pattern of this parameter in the next sub-section.

Table 5: OLS hedonic regression results for 2007 to 2013; plan-day data with linear time interactions

Variables and statistics	**Model 4: Large operators only (>10% market share)**	
Dep. variable	Ln(Monthly price of plan)	
	Coef.	**Robust SE**
lnDownload speed	0.139	0.0278***
lnDownload speed*Time	-0.000752	0.000920
lnUpload speed	-0.00588	0.0394
Contention ratio	-0.000287	0.000724
Cable	-0.604	0.0722***
Datacard	-0.205	0.0733***
DSL	REF	
FTTH or fibrelan	-0.535	0.377
Fixed wireless	0.774	0.0483***
Access type*Time		
Cable*Time	0.0101	0.00295***
Datacard*Time	-0.0395	0.00602***
DSL*Time	REF	
FTTH or fibrelan*Time	0.00869	0.0140
Fixed wireless*Time	0.00785	0.00201***
Transfer limited? [yes=1]	-0.0677	0.0173***
Bundled plan? [yes=1]	0.0926	0.0303***
Bundled plan*Time	-0.00281	0.00163*
Pre-TVsample? [yes=1]	0.0221	0.0189
TV included? [yes=1]	0.395	0.0293***
Quarterly time trend	-0.00884	0.00191***
Constant	4.061	0.0942***
Operators FE	YES	
Operators FE*Time	YES	
Observations	168,100	
Plans	1,156	
Adjusted R-squared	0.795	

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively; standard errors allow for clustering at plan level.*

The upload speed and contention effects lose their statistical significance when the sample is limited to the largest operators. This implies that effects observed in the full-sample results were driven by the characteristics of smaller operators' plans, whereas larger operators tend not to link their prices to these attributes to a significant extent. The price premium on bundled plans remains significant and largely unchanged, and its time interaction term shows the effect to be falling over time as indicated in the earlier models.

Turning to the access type variables, there are some differences from the full sample results. Datacard services again attract a large discount compared to DSL, but cable services have a sizeable discount in Model 4 that shrinks over time. In contrast, FTTH or fibrelan services (for which a discount opened up over time in Models 1 and 2) are not significantly different from DSL in their pricing when only large operators are included. This result suggests that smaller operators are increasingly pricing FTTH at a discount, but large operators are not.

4.3 Marginal price of download speed over time

The linear models discussed so far show that the elasticity of price with respect to download speed fell over time. This change may not have happened in a smooth, linear way. To explore the timing of this change in more detail, we re-estimate Models 2 and 4 with an individual dummy variable for each quarter, each of which is interacted with download speed. This allows the download speed elasticity to vary more flexibly. For simplicity, other time interactions are omitted.[4] Figure 5 below shows the pattern of estimated elasticities for the period from 2007-2013.

[4] Full regression results for the models discussed in this sub-section are available on request from the authors.

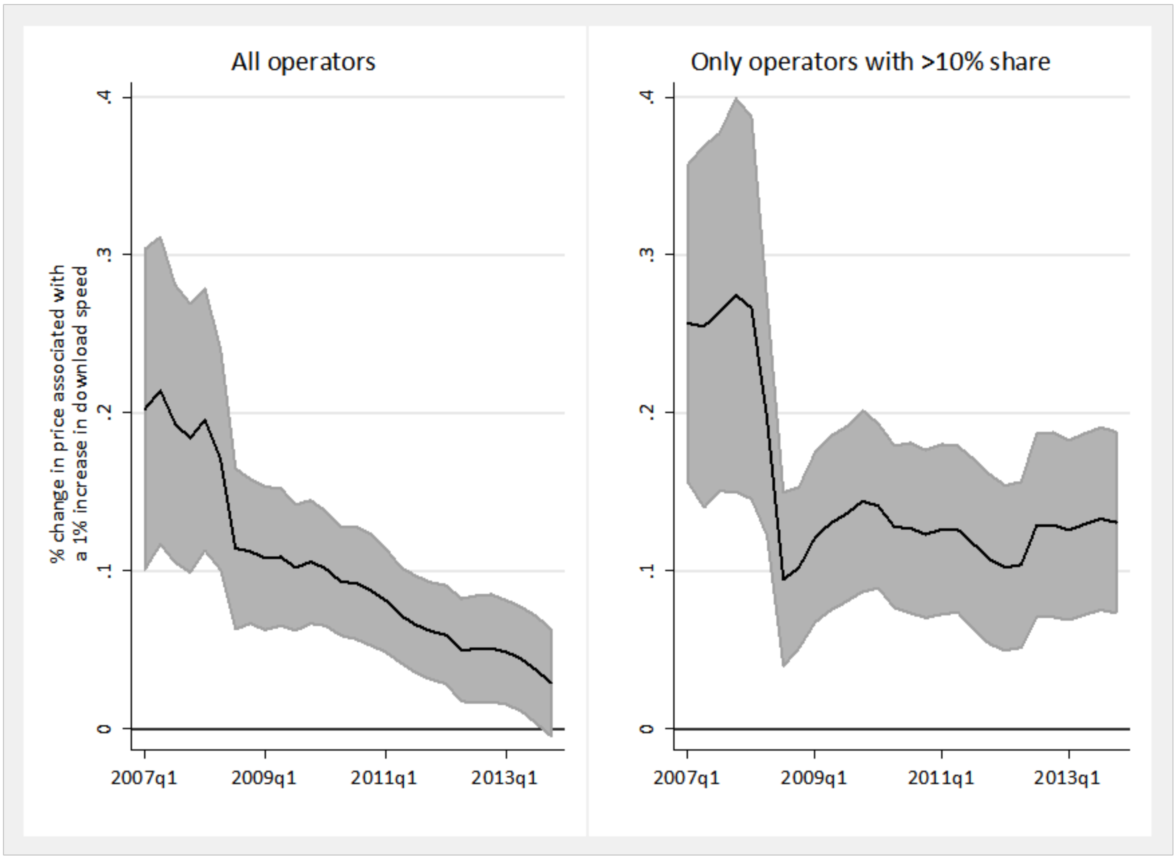

Figure 5. Elasticity of price with respect to download speed; 2007-2013 ; for all plans and for plans offered by large operators

When all plans are included in the sample, the picture is one of steady decline in the download speed elasticity until it is close to zero by the end of 2013. However, if we look only at the subset of plans offered by large operators (i.e. those with at least 10% quarterly market share at some point in the sample period), the estimated elasticity falls sharply in 2008 and is broadly steady at a low but non-zero value thereafter. This suggests that the relationship between download speed and price has continued to weaken among the smallest operators, but that among the main suppliers in the market a measure of stability has emerged.

Driven by the behaviour of smaller operators, average prices of plans now contain little or no premium for incremental download speed, whereas larger operators have continued to charge a small premium.

4.4 Incumbent's retail price premium over time

A similar approach can be used to examine the time profile of changes in the incumbent's average price premium (see Figure 6), which exhibited a negative linear trend over time in the models reported above. Our model estimates an incumbent premium of about 34% at the start of 2007, very much in line with Crocioni and Correa (2012). However, since then it has fallen both for the full sample of plans and for the sub-sample of plans offered by large operators. By the last quarter of 2013, it is estimated to be about 8-9%. By the end of the sample period, the estimated premium is no longer statistically significant.

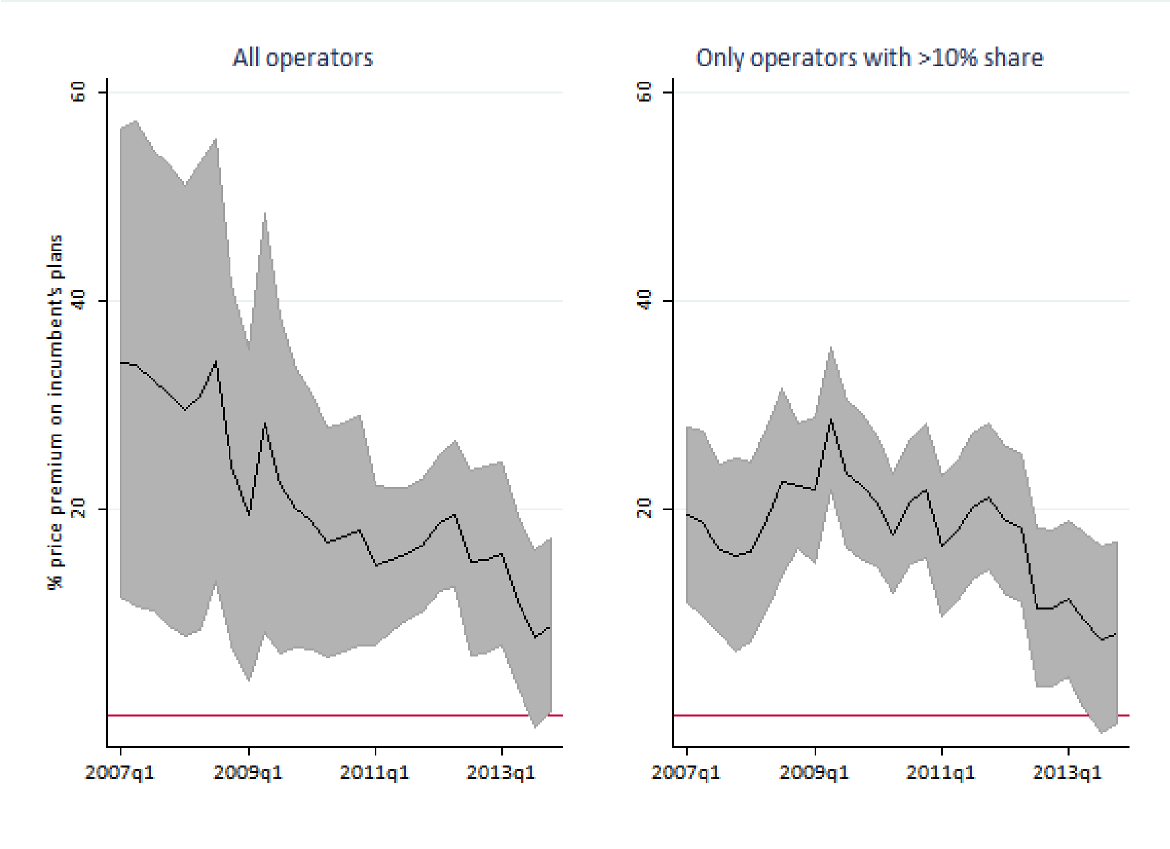

Figure 6. Price premium on fixed line incumbent's broadband plans; 2007-2013; for all plans and for plans offered by large operators

A decline in the incumbent's pricing power in the retail broadband market is one possible explanation for these results, and it would be consistent with a backdrop of continuing market entry by competitors (see Figure 7, which shows the number of operators offering plans over time) and investment in competing infrastructure and services.

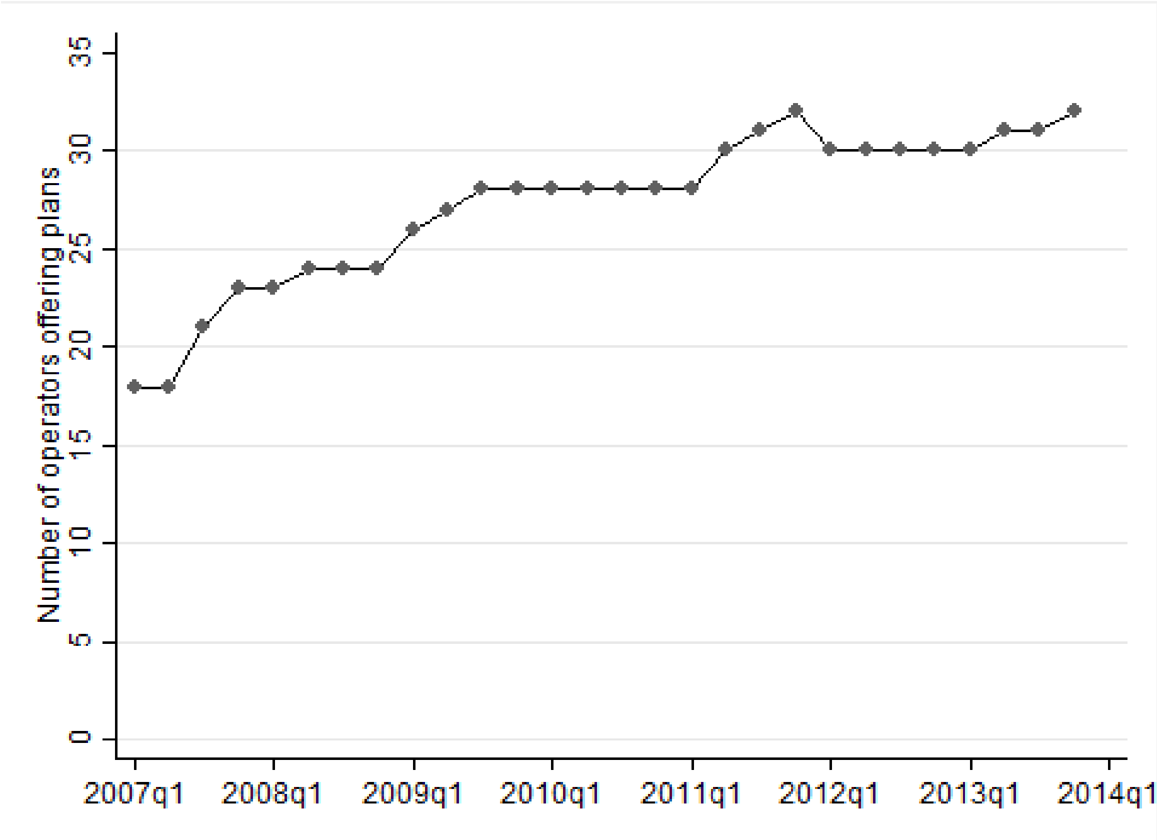

Figure 7. Number of operators offering at least one broadband plan in Ireland during each quarter, 2007-2013

Although the incumbent's market share fell only a modest amount this period (see Table 2 above), the incumbent was also subject to regulation in wholesale broadband and related markets which should have limited any scope to leverage market power into retail markets. The main feature of changing market shares was a doubling in the share of the main operator using cable technology to offer broadband, UPC, which illustrates the strengthening effectiveness of this competitor. In principle, it is also possible that a decline in the incumbent's premium could reflect changes in the relative quality of its services along dimensions not observable in our data (for example, exclusive access to content or quality of customer service). However, we consider it likely that these results are driven at least in part by strengthening rivalry in Ireland's retail broadband market.

4.5 Modelling access technologies separately

Access technologies impose differing cost structures and may experience technical progress and quality improvements along different time profiles. This suggests that time variation in marginal prices may be not always be uniform across technologies. To test for such variations, Table 6 below shows regression results for the parsimonious model (Model 2) re-estimated separately on sub-samples of plans segmented by into three access type categories: DSL, Cable and Other access.

Table 6: OLS hedonic regression results for 2007 to 2013; separate regressions by access technology; same set of explanatory variables as Model 2

Variables and statistics	Model 5: DSL		Model 6: Cable		Model 7: Other access	
Dep. variable	Ln(Monthly price of plan)		Ln(Monthly price of plan)		Ln(Monthly price of plan)	
	Coef.	**Robust SE**	**Coef.**	**Robust SE**	**Coef.**	**Robust SE**
lnDownload speed	0.163	0.0209***	0.279	0.0688***	0.239	0.0467***
lnDownload speed*Time	-0.00392	0.00101***	-0.00334	0.00227	-0.0108	0.00202***
lnUpload speed	0.108	0.0188***	-0.0933	0.0478*	0.0516	0.0328
Contention ratio	0.00315	0.000662***	-0.00672	0.00204***	-0.00604	0.00215***
Transfer limited? [yes=1]	-0.0545	0.0419	-0.0230	0.0515	-0.238	0.0522***
Bundled plan? [yes=1]	0.170	0.0336***	0.0789	0.0816	-0.278	0.0904***
Bundled plan*Time	-0.00751	0.00190***	-0.00183	0.00450	0.0129	0.00537**
Pre-TVsample? [yes=1]	0.0103	0.0141	0.0744	0.0269***	0.0408	0.0188**
TV included? [yes=1]			0.362	0.0279***		
Quarterly time trend	0.000932	0.00260	-0.00388	0.00189**	-0.0390	0.0133***
Constant	3.953	0.0664***	4.025	0.144***	5.468	0.169***
Operators FE	YES		YES		YES	
Operators FE*Time	YES		YES		YES	
Observations	302,262		48,858		174,021	
Plans	1,594		251		499	
Adjusted R-squared	0.445		0.812		0.712	

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively; standard errors allow for clustering at plan level.*

In Section 2 we noted results in Greenstein and McDevitt (2011) that the download speed coefficient for cable services was consistent between the two periods they studied (2004-6 and 2007-9), whereas the DSL coefficient went from being positive to insignificant. Comparing Models 6 and 7 above, we find a similar pattern of effects: Cable has a higher download speed elasticity of about 0.28 with no significant time interaction, while DSL starts at 0.16 and falls over time. Other access technologies are closer to the DSL pattern. These differences may arise due to cost structures; e.g. the marginal cost of supplying download speed on cable networks could be higher than on other technologies. Or cable operators may be able to maintain a higher premium on incremental download speed because their customers are more willing to pay it. Unfortunately we cannot distinguish between these supply- and demand-side explanations with the available data.

Upload speed has the expected positive elasticity for DSL, but is not statistically significant for cable and other access types. Perhaps this reflects differences in the types of users or applications prevalent on each access type. Transfer limits seem to attract a statistically significant discount only on technologies other than cable and DSL. Congestion might have been more of a problem on wireless networks than wired ones in this period, implying higher costs from heavy data users. Bundles also attract a substantial (though weakening) discount from suppliers of other forms of access, in contrast to the positive but falling coefficient for DSL and the insignificant one for cable.

5. Conclusions

Modelling the prices of broadband plans offered in Ireland from 2007 to 2013, we have been able to identify a mixture of stable and time-varying relationships between broadband prices and plan characteristics. During this period, the elasticity of price with respect to download speed fell, particularly for smaller operators, those not using cable technology and in the earlier part of the period. The elasticity for most operators (apart from those using cable) is now very low, suggesting that operators feel unable to charge much of a premium for high speed services. Public policy in Europe and elsewhere places a high value on attaining universal availability of high speed services, but this result emphasises the difficulty of obtaining extra revenue from consumers to finance further substantial speed improvements.

In common with Wallsten and Riso (2015), we find that plans with limits on data transfer have lower prices, at least for operators using wireless technologies, but in contrast with their work we do not find a statistically significant price effect from contracts. Our result may be due to the limited availability of broadband plans without contracts or contract periods in Ireland, leading to too little sample variation for us to pick up an effect. Increments to upload speed have a price premium only when smaller operators are included.

Bundled services also show a price premium for DSL-based services (and for large operators in general), but we find a discount among plans provided using other forms of access apart from those using cable, which exhibit no significant effect. Among both DSL and other access methods, the price effect of bundling has been weakening in absolute terms. The significant decline in this premium over time among DSL plans suggests either a reduction in the relative valuation or cost of other services offered within the bundle compared to the broadband connectivity component or an increase in consumer price sensitivity within the segment. The data available to us do not allow us to test these competing explanations.

The discount FTTH/fibrelan services identified by Calzada and Martínez-Santos (2014) seems have emerged over time in Ireland and is only statistically significant when small operators are included. However, TV service bundled with broadband does attract a substantial (c. 40%) premium as expected.

The incumbent’s retail price premium has fallen significantly since 2007. This seems consistent with strengthening competition in retail broadband services. Removal of price controls from Europe’s retail broadband markets was motivated at least partly by the belief that the incumbent no longer held significant market power; this result provides supporting evidence for that view.

The overall impression given by these results is of maturing retail broadband market that now offers little or no incumbency premium and applies lower price increments to some aspects of service quality than were observed in the past. Smaller providers do still behave somewhat differently from larger ones, e.g. offering discounts on fibre-based services, and some differences in marginal pricing behaviour remain across access technologies.

For regulators, the maturing of the retail broadband services market has allowed a shift in focus from controlling an incumbent firm’s market power to enhancing consumer protection in the face of increasingly varied and complex service offerings. For government departments tasked with advancing information society objectives, the falling price premium on incremental download speed suggests it may be difficult to get consumers in underserved areas to contribute much towards higher quality service.

Data from price comparison websites offers a rich source of evidence on pricing in retail telecoms markets. Regulators may intervene to ensure the quality and completeness of these data with a view to improving consumer protection, but a by-product of this intervention is the potential for better quality and accessibility of data for research.

The biggest missing piece, however, is the level of demand associated with each plan. If these data could be added or matched in from other administrative sources, it would be possible to say more about demand parameters, analyse competitive dynamics and even estimate marginal costs using structural market models.

Another potentially fruitful avenue for research is into the behavioural effects of price comparison sites. If data on consumer queries to these sites could be linked to subsequent purchasing behaviour, we might learn a lot about how site design and the structure of prices affects consumer demand and the optimality of choices.

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Annex: Additional regression results

Table A1 shows results for a regression model with download speed and its squared value included in levels rather than log terms. The interaction between download speed and time is also excluded; the model is otherwise the same as Model 2 (the parsimonious version).

Table A1: OLS hedonic regression results for 2007 to 2013; semi-log relationship between speed and prices

Variables and statistics	**Model 8: Semi-log speed-price relationship**	
Dep. variable	Ln(Monthly price of plan)	
	Coef.	**Robust SE**
Download speed (Mb/s)	0.0123	0.00164***
Download speed^2	-6.33e-05	1.04e-05***
Upload speed (Mb/s)	0.0210	0.00664***
Contention ratio	8.13e-05	0.000727
Access type		
Cable	-0.137	0.0865
Datacard	-0.414	0.138***
DSL	REF	
FTTH or fibrelan	0.519	0.164***
Fixed wireless	-0.109	0.0606*
Access type*Time		
Cable*Time	-0.00211	0.00361
Datacard*Time	-0.0273	0.00876***
DSL*Time		
FTTH or fibrelan*Time	-0.0425	0.00875***
Fixed wireless*Time	0.00427	0.00280
Transfer limited? [yes=1]	-0.105	0.0368***
Bundled plan? [yes=1]	0.144	0.0362***
Bundled plan*Time	-0.00610	0.00188***
Pre-TVsample? [yes=1]	-0.0124	0.0107
TV included? [yes=1]	0.347	0.0484***
Quarterly time trend	-0.00679	0.00290**
Constant	4.182	0.101***
Operators FE	YES	
Operators FE*Time	YES	
Observations	525,141	
Plans	2,344	
Adjusted R-squared	0.509	

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively; standard errors allow for clustering at plan level.*