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1 July 2015

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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. We augment our results by restricting the analysis to large operators and also by weighting by operator market share for a subset of our data (2010-2013). 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 plans declined during the sample period. In addition, the retail price premium enjoyed by the incumbent operator fell significantly since 2007.

JEL classifications: L11, L96

Key words: broadband services, market analysis, Ireland

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. Considerable research has been done on the determinants of investment, the socioeconomic benefits of broadband availability and the effects of regulation and state support on the development of broadband infrastructure. Less is known about how operators package and price infrastructure and value added services into retail offerings, and how such services are evolving over time.

On the face of it, this relative lack of research on retail markets makes sense: retail broadband services are generally not subject to economic regulation in developed countries, with regulatory intervention limited to consumer protection, provision of information and initiatives to assist under-served areas and user segments. If markets are effectively competitive, one might reasonably assume competitive forces will yield an efficient outcome for consumers.

Yet many jurisdictions do not limit broadband policy to encouraging availability of infrastructure, they also wish to encourage take-up of services; indeed, some argue that the focus of policy should shift from infrastructure availability towards adoption (e.g. Whitaker, Gallardo and Strover, 2014). The characteristics of retail services undoubtedly affect consumer decisions about service adoption and determine the nature of the services they obtain.

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. 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 average nominal broadband prices of broadband plans in Ireland were static this period, implying a significant fall in real prices given that quality was improving. 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 plans declined during the sample period. In addition, the retail price premium enjoyed by the incumbent operator fell significantly since 2007.

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 (2015) estimate a linear hedonic model on over 25,000 broadband prices drawn from all OECD countries from 2007 to 2009. 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 & Martinez-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 & 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 (Crocioni & Correa, 2012). These countries were chosen because Ireland had limited broadband infrastructure competition at the time while the Netherlands enjoyed a high degree of infrastructure competition. For Ireland, Crocioni & Correa (2012) found that the market incumbent for DSL (Eircom) had substantial pricing power. For the Netherlands, the authors found the incumbent operator held slight pricing power at best.

A few papers allow for the possibility of temporal change in coefficients. Lyons & 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 & 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 consumer price indices. They find that the market has seen only limited price reductions in real terms, in contrast to the rapid price decline observed for consumer electronics (such as personal computers). The paper includes results for models run separately on sub-samples from 2004-6 and 2007-9. These results suggest that changes occurred in a several coefficients between periods, including those for broadband speed and regional effects. However, the authors do not discuss these apparent changes in detail.

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.

In a second round of models, 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.

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 Commission for Communications Regulation (ComReg) is the Irish regulator for telecommunications, radio and broadcasting markets in Ireland. The main dataset for this paper is drawn from Callcosts.ie, a price comparison website maintained by 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 so consumers receive up-to-date information on the products available. The Callcosts data contains information on the price and qualitative features (advertised connection speeds, data allowances etc.) of each plan.

Although the data available ranges from 2006 to the present, we restrict the sample to the period from 2007 on to avoid the early start-up phase. 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]. Although county-level availability information is also stored in the Callcosts database, historical information is not retained and we have access to data for only two time points. As a result, our analysis is carried out at national level.

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).

Price promotions are used in the market, often in the form of an introductory discount. Although the Callcosts system collects some information on promotions, unfortunately historical data are not retained. As a result we are not able to take price promotions into account.

[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'.

Download and Upload Speed

The Callcosts dataset lists the *advertised* download and upload speeds for each plan (in Mbit/s), which does not necessarily reflect the actual speed customers experience. Broadband technologies differ greatly in the speeds and contention levels they can offer, while local conditions and network specificities influence the relationship between actual and advertised speeds. Unfortunately, no data is available on actual data transmission speeds for the plans in our dataset. 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

To illustrate the prevalence of access technologies used to deliver broadband in Ireland, Table 1 reports the number of active broadband subscriptions for Q1 2014. Total active broadband subscriptions rise year on year by 1.8%, with the largest growth in VDSL services, reported separately from typical DSL subscriptions since Q3 2013.

Table 1: Broadband access type - active subscriptions

	2014 Q1 Subscriptions	**Quarterly Growth Rate 2013 Q4 - 2014 Q1**	**Year-on-Year Growth Rate 2013 Q1-2014 Q1**
Cable	351,267	+2.9%	+10.3%
Datacard	488,979	-2.2%	-9.9%
DSL	687,049	-2.0%	-6.0%
vDSL	103,420	+38.7%	N/A
Fibre & Satellite	12,015	+0.1%	-5.1%
Wireless	58,984	-2.4%	-7.8%
Total Fixed Broadband	1,212,735	+2.0%	+7.7%
Total Narrowband	8,281	-3.3%	-20.5%
Total Internet Subscriptions	**1,709,995**	**+0.7%**	**+1.8%**

Source: ComReg (2014)

For modelling purposes we group technologies into five access type categories (With Fibre and Fibrelan grouped together, DSL and VDSL grouped, and Satellite omitted). Table 2 shows the number of unique plans in our sample sorted by technology.

Table 2: Number of unique plans by technology and download speed in sample

	<2 Mbit/s	2-5 Mbit/s	5-10 Mbit/s	10-50 Mbit/s	>50 Mbit/s	Total	Percentage
Cable	36	27	12	92	84	**251**	10.7
Datacard	0	61	62	0	0	**123**	5.25
DSL	371	442	472	305	4	**1,594**	68.0
Fibre	0	0	4	16	32	**52**	2.22
Wireless	99	108	82	35	0	**324**	13.8
Total	**506**	**638**	**632**	**448**	**120**	**2,344**	100

DSL service is used as the reference category, because it remains the most prevalent access type. It should also be noted that different broadband technologies serve different purposes for customers. For example, both Datacard and DSL offer very different speed ranges, but Datacard offers more portability than DSL and are typically cheaper. Technologies have differing geographical availability, with cable and fibre largely restricted to urban areas. Because cost structures, geographical availability and unobserved quality attributes vary by technology, we expect that access type may have a significant association with price. Since the dependent variable is in logs, the access type coefficients represent the percentage premium in price each access type commands over the reference category (DSL).

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. The sample contains considerable variation in contention by technology, with DSL connections advertised as having the highest contention ratio on average. Contention is not reported for datacard plans in the Callcosts database and we have no other source of data on contention ratios among these services, so we set the value for such plans to the mean of the wireless category (27.6).

Operator Group

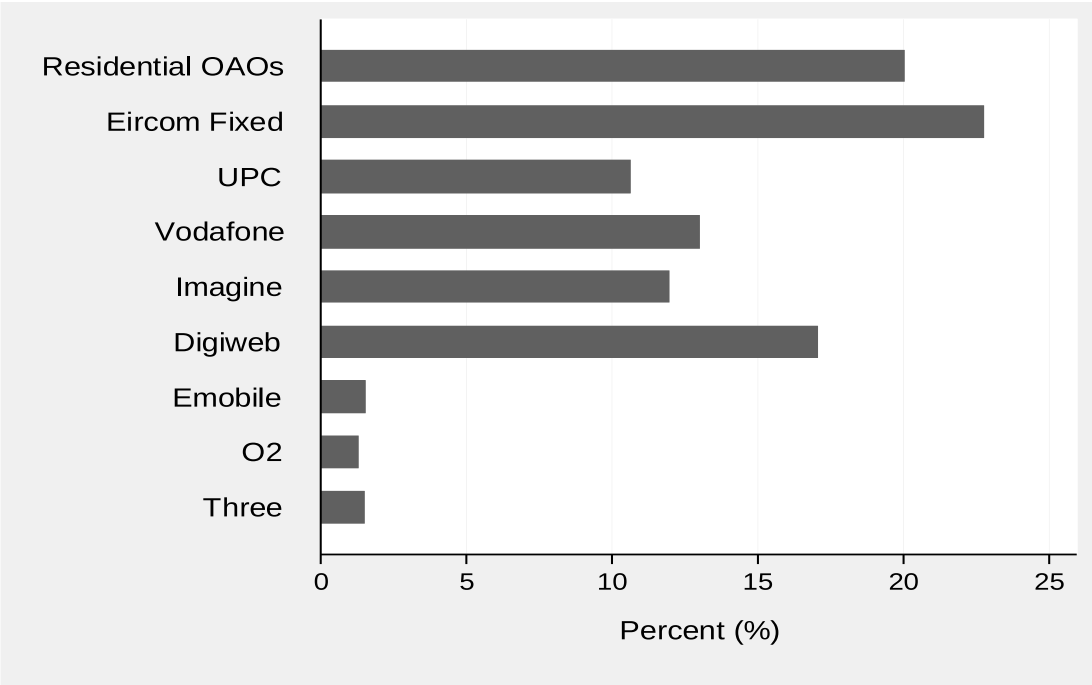
The final dataset contains 37 operators, we which group into nine categories. Eircom is the historical incumbent retail broadband provider in Ireland. In line with EU policy, Ireland's regulator ComReg does not apply economic regulation to Eircom's broadband services at the retail level. However, ComReg has deemed Eircom to have significant market power (SMP) at the wholesale level and applies a set of regulatory measures (ComReg, 2010).

This variable denotes the operator to which each plan belongs. Over our sample period some providers have acquired others, so we group them accordingly for the modelling purposes:

1. Other Authorised Residential Operators (Residential OAO's)
2. Residential broadband packages offered by Eircom (Eircom Fixed)
3. UPC
4. Residential and Datacard packages offered by Vodafone (Vodafone)
5. Imagine Broadband
6. Digiweb
7. Datacard packages offered by E-Mobile and Meteor (Emobile)
8. Datacard packages offered by O2
9. Datacard packages offered by Three

Figure 1 shows the distribution of unique plans by operator group. 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).

Figure 1: Share of plans from each operator group in the sample



Operator market shares

Similar to Greenstein & 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.[2] We use these shares to estimate market-share weighted regression models for comparison with the basic specification in which all plans are given equal weight.

[2] 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 offered to residential customers.

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 lists summary statistics for each of the variables used in our empirical analysis.

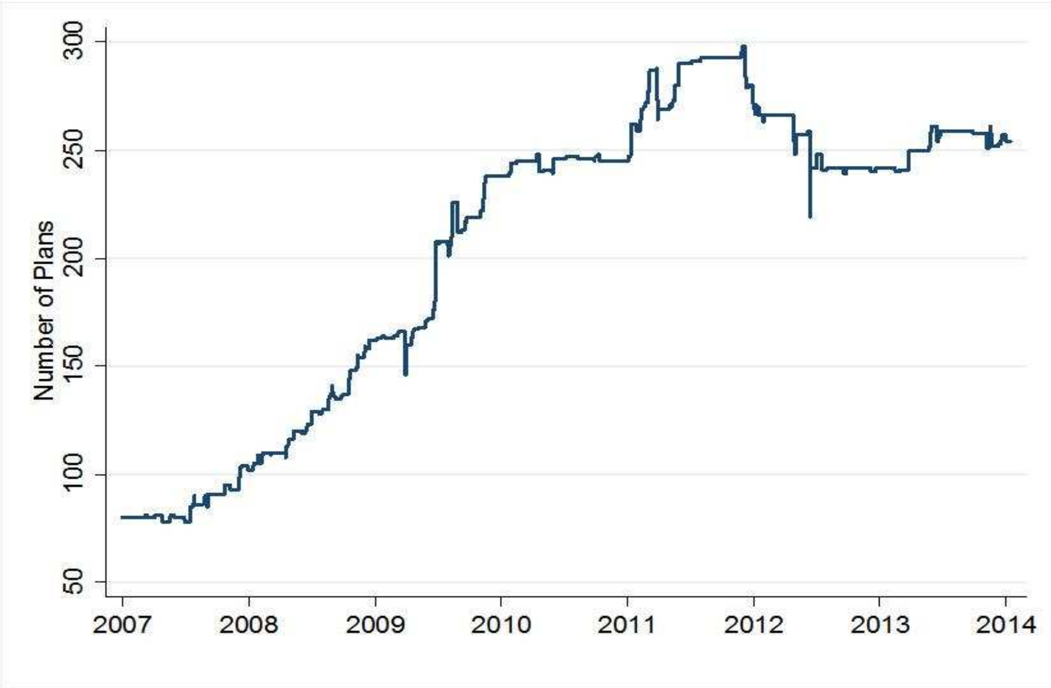
Table 3: Descriptive statistics for samples

	Full sample (525,141 plan-days)		Sample 2010 Q1 to 2014 Q1 (376,571 plan-days)	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Monthly Price (€)	52.0	18.8	51.6	18.8
Download speed Mbit/s	9.19	17.3	11.3	19.9
Upload speed Mbit/s	1.07	2.11	1.21	2.35
Contention Ratio (reciprocal)	26.7	18.7	25.0	18.9
Transfer Limited [1/0]	0.692	0.462	0.714	0.452
Transfer Limit (Gb)	48.2	105	60.9	121
Bundled [1/0]	0.439	0.496	0.453	0.498
Contract [1/0]	0.989	0.105	0.986	0.119
Min. contract length (Months)	11.4	2.37	11.7	2.23
Pre TV sample [1/0]	0.137	0.343	0.191	0.393
TV included [1/0]	0.00433	0.0657	0.00604	0.0775

4. Results

Figure 1 displays the number of plans available over time according to Callcosts. We observe the number of plans rising 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.

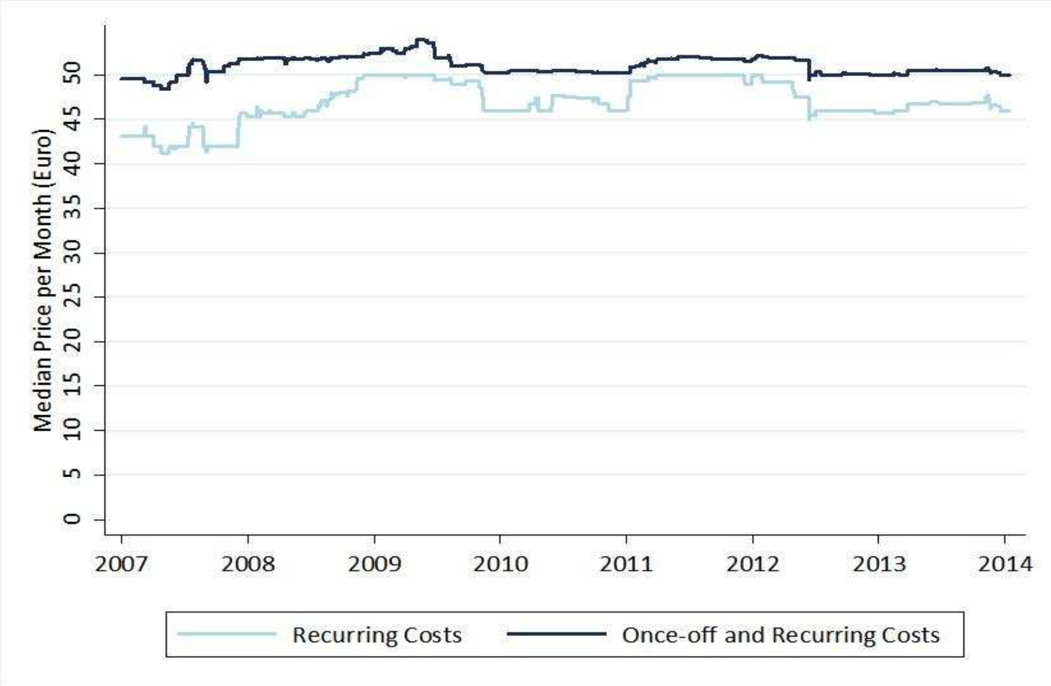
Figure 2: Number of plans over time



Source: Callcosts.ie data

The average nominal price of broadband services in Ireland has been remarkably stable over time. Figure 2 displays the median monthly price of broadband plans, including and excluding an allowance for annualised once-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.

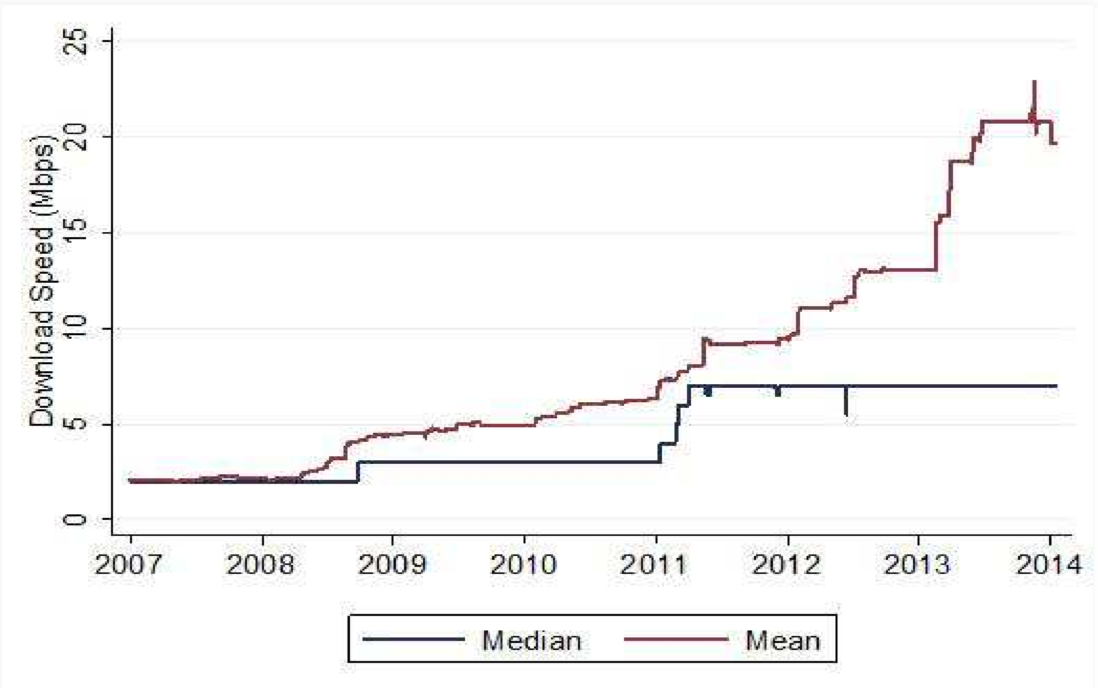
Figure 3: Median plan price per month



Source: Callcosts.ie data

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: Median and Mean Download Speed



Source: Callcosts.ie data

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 (Figure 1). Technology upgrades seem to have induced or coincided with market changes, whereby operators revamped their product offerings with a significantly improved product offered at a broadly similar price (i.e. the average prices shown Figure 2 did not increase in line with the average download speed in Figure 3). Such market changes also affected existing as well as new customers. For example, in 2010, Eircom upgraded existing customers on a 1Mb, 3Mb or 7Mb plan to an 8Mb plan during the launch of their 'Next Generation Broadband' scheme (Eircom, 2010).

4.1 Regression results – full sample

In the remainder of this section we report hedonic regression results for the model set out in sub-section 3.1. The regressions shown in Table 4 allow for time varying effects for 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 sample; plan-day data with linear time interactions; full model compared to parsimonious version				
Variables and statistics	**Model 1: All variables**		**Model 2: Parsimonious version**	
Dep. variable	Monthly price of plan		Monthly price of plan	
	Coef.	**Robust SE**	**Coef.**	**Robust SE**
lnDownload speed	0.149	0.0296***	0.139	0.0232***
lnDownload speed*Time	-0.00430	0.00150***	-0.00352	0.000912***
lnUpload speed	0.0634	0.0389	0.0945	0.0245***
lnUpload speed*Time	0.00196	0.00175		
Contention ratio	-0.000685	0.00160	0.00165	0.000793**
Contention ratio*Time	0.000131	6.99e-05*		
Access type				
Cable	0.137	0.0872	0.0654	0.0799
Datacard	-0.605	0.146***	-0.538	0.148***
DSL	REF		REF	
FTTH or fibrelan	0.0727	0.152	0.0503	0.140
Wireless	-0.0493	0.0584	-0.0708	0.0624
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**
Wireless*Time	0.000340	0.00279	0.00206	0.00268
Transfer limited? [yes=1]	0.00144	0.0661	-0.0789	0.0376**
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***
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**
TV included? [yes=1]	0.394	0.0492***	0.407	0.0422***
Time	-0.00920	0.0137	-0.00675	0.00356*
Constant	4.359	0.270***	4.213	0.123***
Operators FE	YES		YES	
Operators FE*Time	YES		YES	
Observations	525,141		525,141	
Plans	2,344		2,344	
Adjusted R-squared	0.571		0.568	
*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 (2012). 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. This price premium may be explained by the extra cost and perceived value of the additional features offered in bundled plans, or the segments of the market served by bundles may exhibit less consumer switching as shown for UK communications services by Burnett (2014). The data available to us do not allow us to test the relative importance of these explanations. The significant decline in this premium over time suggests either a reduction in the relative valuation or cost of services offered within the bundle compared to the broadband connectivity component or an increase in consumer price sensitivity within the segment.

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 and 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 more widely available in 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 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; this effect may be an artefact of some association between contention and technology or other service characteristics that is imperfectly captured by our parameters.

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.

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. This information is used in two ways. We re-run Model 2 for the shorter sample period and compare results with and without sample weights. In Annex 1, we also report results for Model 2 run over the full sample period but with a sample restricted only to large operators, thus eliminating plans of operators that had few subscribers but weighting plans of large operators equally.

The variants we model are summarised in Table 5 below.

Table 5: Sample and weighting variants used in estimation

Variant	Description
Full sample period with all operators	This variant uses all available microdata, with each plan-day representing one observation.
Large operators only	This includes only operators that served >= 10% of the market in at least one calendar quarter.
Weighted by operator market share, 2010-2013	Here each observation is weighted by its operator's quarterly market share. Because market share data are published only from 2010 onwards, this variant has a limited sample period of 2010 Q1 to 2014 Q1.

Table 6 shows the results with market share weights. The download elasticity is lower in this model both with and without weights, which we would expect because this sub-sample represents the later part of the full sample and we have previously shown that the download speed elasticity was falling. In this case, the time interaction is not significant, so it seems that the fall in the elasticity must have happened in the earlier part of the full sample period. We will say more on this shortly.

The upload speed and contention effects lose their statistical significance when market share weights are applied or the sample is limited to the largest operator (Model 5 in Annex 1). 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 picture is more complex for the price premium on bundled plans. It loses statistical significance when market share weighting is applied, but remains significant and largely unchanged when the sample is restricted to large operators but the sample period is longer (in Model 5, Annex 1). We noted earlier that this effect was falling over time, so its lack of significance in Model 4 may imply that it fell more for large firms that small ones in the earlier part of the full sample period.

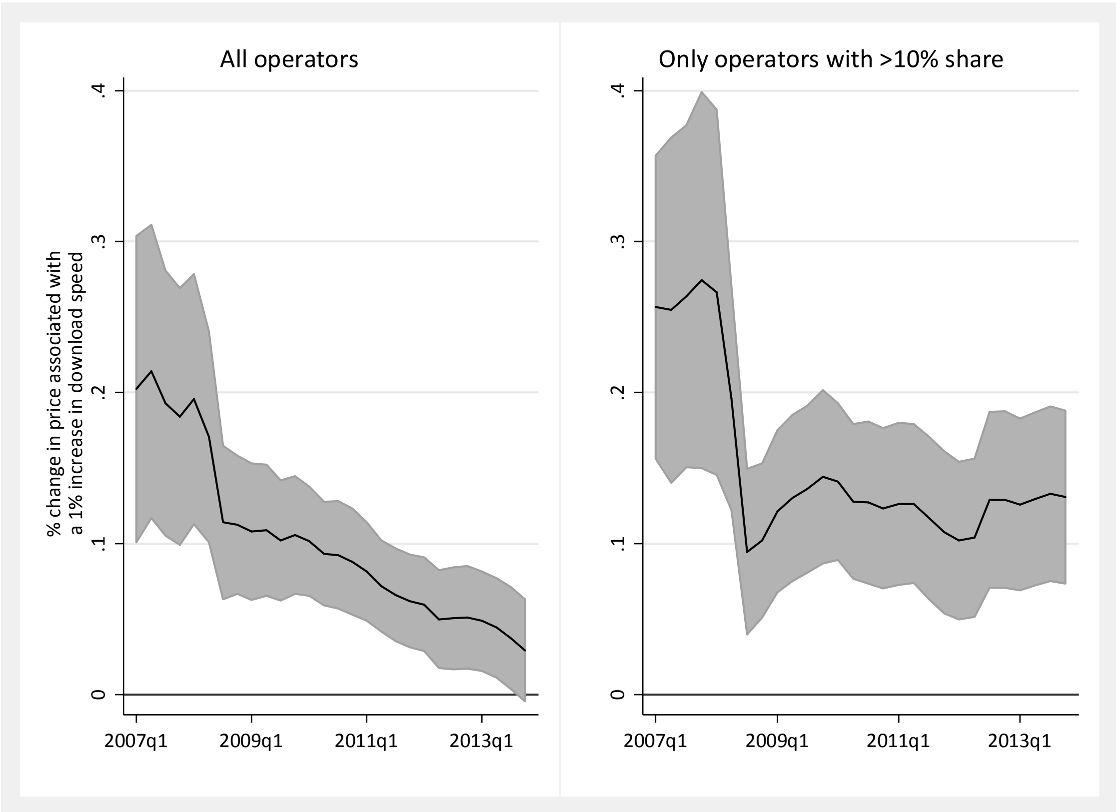
Table 6: OLS hedonic regression results for 2010 to 2013 sample; Parsimonious model (Model 2) with and without weighting by quarterly market shares				
Variables and statistics	**Model 3: Unweighted**		**Model 4: Market share weights**	
Dep. variable	Ln(Monthly price of plan)		Ln(Monthly price of plan)	
	Coef.	**Robust SE**	**Coef.**	**Robust SE**
lnDownload speed	0.0952	0.0284***	0.0635	0.0253**
lnDownload speed*Time	-0.00184	0.00117	0.000922	0.00129
lnUpload speed	0.108	0.0271***	0.0351	0.0433
Contention ratio	0.00212	0.000741***	0.00104	0.000649
Access type				
Cable	0.0193	0.0927	-0.0623	0.0971
Datacard	-0.981	0.158***	-0.786	0.152***
DSL	REF		REF	
FTTH or fibrelan	0.183	0.150	0.417	0.155***
Wireless	-0.136	0.0812*	-0.0552	0.133
Access type*Time				
Cable*Time	-0.00468	0.00386	0.00229	0.00501
Datacard*Time	-0.00279	0.00851	-0.00678	0.00868
DSL*Time	REF		REF	
FTTH or fibrelan*Time	-0.0227	0.00725***	-0.0275	0.00620***
Wireless*Time	0.00415	0.00352	0.00963	0.00355***
Transfer limited? [yes=1]	-0.103	0.0413**	-0.133	0.0320***
Bundled plan? [yes=1]	0.116	0.0568**	0.0419	0.0456
Bundled plan*Time	-0.00477	0.00285*	-0.00199	0.00215
Pre-TVsample? [yes=1]	-0.0107	0.0100	-0.0319	0.0117***
TV included? [yes=1]	0.402	0.0419***	0.420	0.0376***
Time	-0.00315	0.00323	-0.00951	0.00324***
Constant	4.172	0.110***	4.254	0.0920***
Operators FE	YES		YES	
Operators FE*Time	YES		YES	
Observations	376,571		376,571	
Plans	1,541		1,541	
Adjusted R-squared	0.604		0.653	
*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively; standard errors allow for clustering at plan level.*				

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 the coefficient on FTTH or fibrelan services are very different between the unweighted and weighted models. The price premium on FTTH/fibrelan plans compared to DSL is positive and statistically significant in the weighed regression, but as in the unweighted and full-sample cases it is falling slowly over time. This result might be driven by a smaller FTTH price premium among small operators than among large ones.

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 the model 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.[3] Figure 5 below shows the pattern of estimated elasticities for the full sample period of 2007-2013.

Figure 5: % change in price associated with a 1% increase in download speed over time, 2007-2013, comparing sample with all operators to one with only large operators



Note: shaded area shows 95% confidence interval

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

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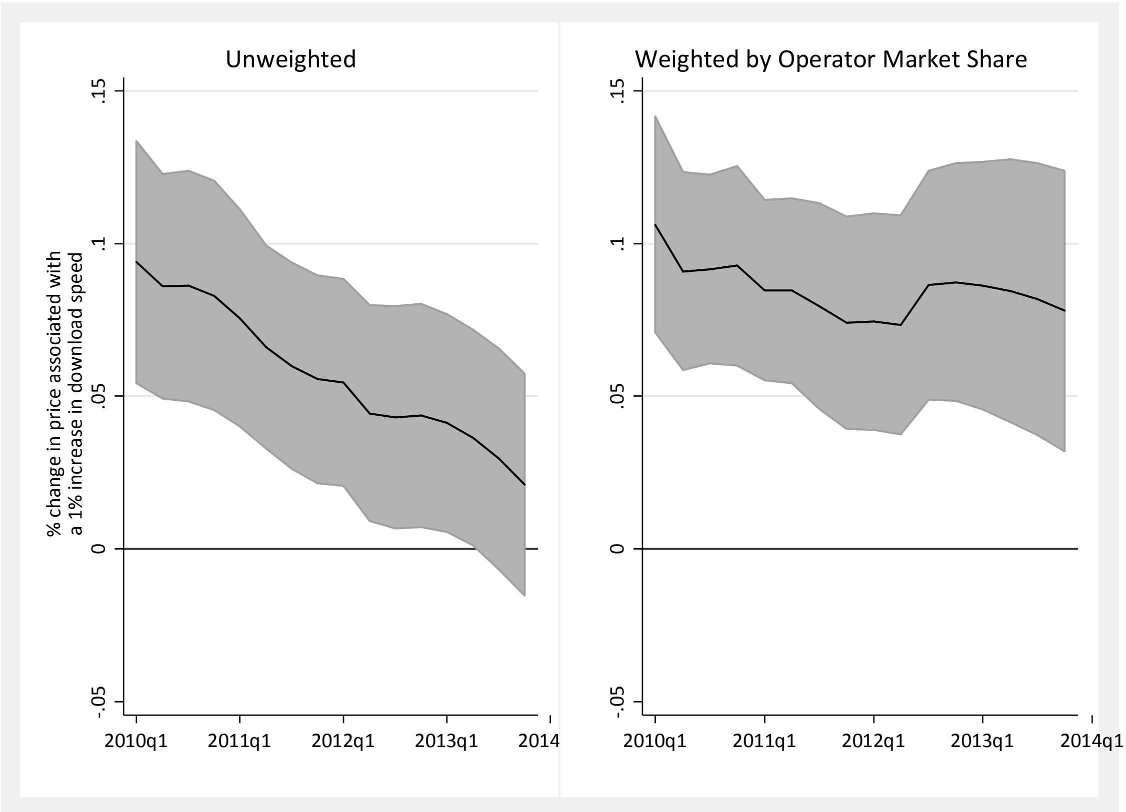
[3] Full regression results for the models discussed in this sub-section are available on request from the authors.

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.

If we view this comparison using market share weights (available for the more limited period of 2010-2013; see Figure 6), it seems that the elasticity has continued to decline somewhat among larger suppliers, although there is still a much greater estimated decline if we give all plans equal weight. 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 despite a gradual continuing decline.

Figure 6: % change in price associated with a 1% increase in download speed over time, 2010 to 2013, unweighted and weighted by quarterly market shares

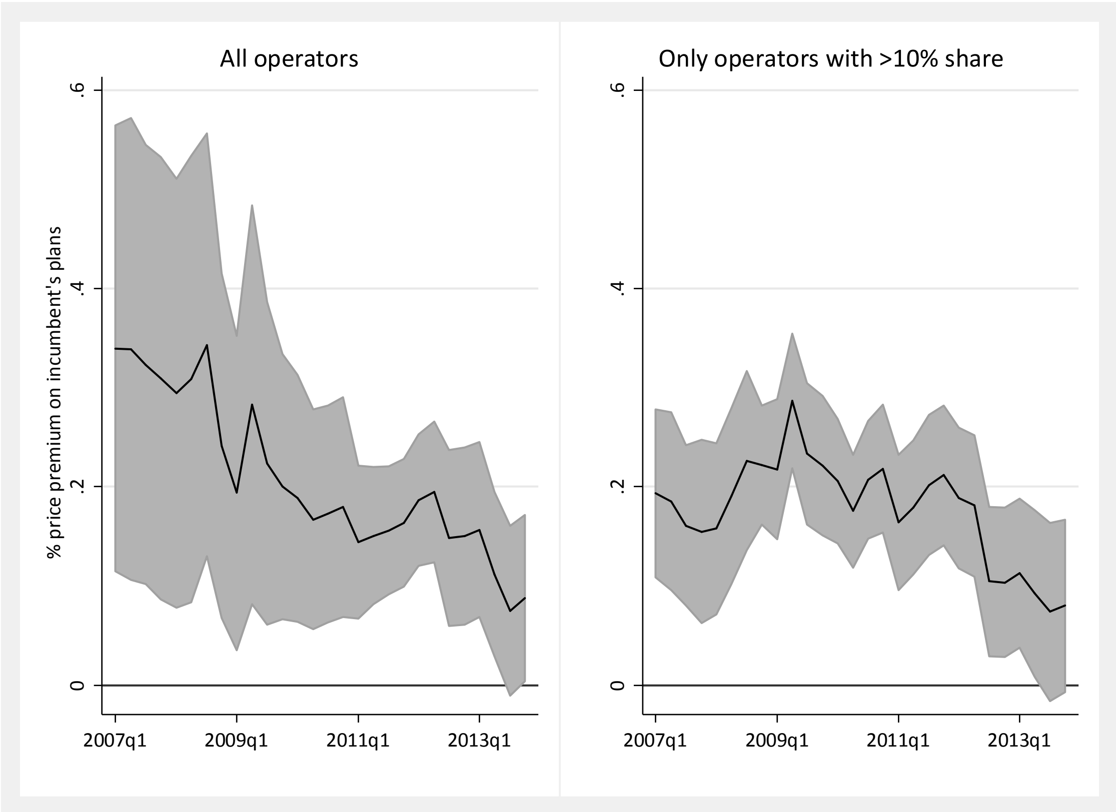


Note: shaded area shows 95% confidence interval

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, which (like download speed) showed 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%.

Figure 7: % price premium on incumbent's plans over time, comparing sample with all operators to one those with >10% market share in 2011 Q1



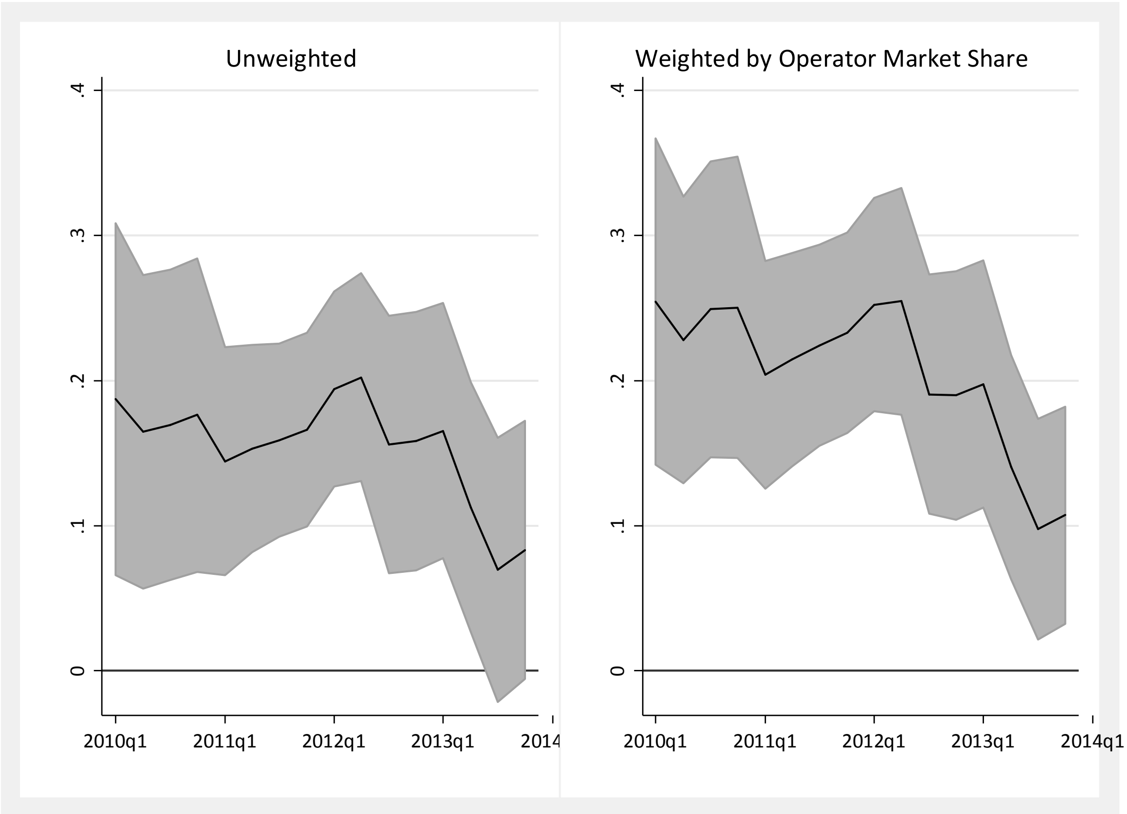
Note: shaded area shows 95% confidence interval

Again applying the alternative strategy of weighting by market share (Figure 7) gives a picture similar to the sample of large operators. It seems that 2012 marked a structural break, after which a period of relative stability in the incumbent premium gave way to renewed decline. By the end of the sample period, the estimated premium is statistically significant in only one of the four models shown here.

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 and investment in competing infrastructure and services. The incumbent was also subject to regulation in wholesale broadband and related markets throughout this period, which should have limited any scope to leverage market power into retail markets. 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.

Figure 8: % price premium on incumbent's plans over time, 2010-2013, unweighted and weighted by quarterly market shares



Note: shaded area shows 95% confidence interval

5. Conclusions

Estimating hedonic models on daily data on 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, but it fell most for smaller operators and in the earlier part of the period. The elasticity 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 extracting 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, 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 in Ireland, leading to too little sample variation for us to pick up an effect.

Increments to upload speed have a price premium only for smaller operators. Bundled services also show a price premium, but it has been declining over time (especially for larger operators). In contrast to Calzada & Martínez-Santos (2014), we find a premium on FTTH/fibrelan services, at least among large operators and at the end of the sample period, although it too seems to be falling over time. Also by the end of our sample, cable services seem to be priced at similar levels to equivalent DSL offerings. However, TV service bundled with broadband does attract a substantial premium as expected.

The incumbent's retail price premium first estimated by Crocioni and Correa (2012) has fallen significantly since 2007. This seems consistent with strengthening competition in retail broadband services over time.

5.1 Some caveats

As ever, this sort of analysis could be considerably improved with better data. 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. To proxy for the level of subscribers to each plan, we have used quarterly market shares and applied this uniformly across each operator's plans. This overstates the importance of characteristics of little-used plans offered by big operators, and under-weights popular plans sold by small operators.

A second important omission is temporary promotions. Some promotional activity is listed on Callcosts.ie, but historical promotions are not stored systematically. Promotions are important in the market, because many subscriptions arise from doorstep or telephone sales of plans with substantial introductory discounts. Our results are based on list prices only.

Another problem with our data (in common with most of the existing literature) is that our dataset lists advertised, not actual, download speeds. When analysing the quality of broadband packages, it would be beneficial to have a more accurate estimate of the speeds customers can expect to receive. SamKnows conducted research into actual and advertised speeds in a pan-EU survey of the performance of residential broadband by installing monitoring units into homes. In October 2013, Ireland's ratio of average actual DSL speed to average advertised speeds during peak periods was 49.98%, far below the EU average of

71.2%. For cable, Ireland's average actual/advertised ratio of 85.1% is far closer to the EU average actual/advertised ratio of 89.3% (SamKnows Limited, 2014).

Sample selection may be imperfect too. Although ComReg believes the vast majority of plans are accounted for (ComReg, 2014), there may be a degree of selection bias present because participation by operators was voluntary. This problem could manifest itself as certain operators not listing their plans or not updating their selection of plans promptly.

Acknowledgements

This research was funded by the ESRI Programme of Research in Communications, with contributions from Ireland's Department for Communications, Energy and Natural Resources and the Commission for Communications Regulation. We are grateful for comments from participants at the 2015 International Telecommunications Society European Regional Conference and an ESRI seminar. The usual disclaimer applies.

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Annex 1 – Regression with full sample period, restricted to large operators

Table 7: OLS hedonic regression results for 2007 to 2013 sample restricted to large operators; Parsimonious model (Model 2)		
Variables and statistics	**Model 5: Large operators, full sample period**	
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
Access type		
Cable	-0.604	0.0722***
Datacard	-0.205	0.0733***
DSL	REF	
FTTH or fibrelan	-0.535	0.377
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
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***
Time	-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.*		