ESRI

Working Paper No. 432

March 2012

Timing and Determinants of Local Residential Broadband Adoption: Evidence from Ireland

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Subsequently published in Empirical Economics, Published online 1 January 2014

Abstract: This article examines the time path of broadband adoption for households in areas that are offered broadband service for the first time and the socioeconomic characteristics of broadband users generally. Using cross-sectional data on broadband take-up and socioeconomic characteristics of small areas in Ireland, linked to GIS data on ADSL availability over time, I find that local penetration growth rates are elevated immediately after service is offered. Local growth rates then decline towards the national average, reaching it after about 3.5 years. The article also includes estimates of the effect of various household characteristics on adoption, finding effects broadly consistent with previous literature. Simultaneity in demand and supply are addressed using 2SLS regression.

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1. Introduction

The research question in this article concerns how quickly residential broadband adoption rises following an improvement in the local availability of broadband services and what socioeconomic factors influence the level of adoption in a small, low-density European country: Ireland. The expected time pattern of residential adoption following introduction of broadband services to an area affects the present value of the benefits from investment in a given area. Faster adoption implies a stronger case for investment, *ceteris paribus*. Information on the characteristics of adopters and non-adopters can also inform the case for public intervention in broadband supply as well as the scope for complementary policies such as educational measures.

Addressing this question requires data on who adopts broadband, their household characteristics and the local availability of broadband services over time. This article focuses on the Republic of Ireland, using data drawn from two main sources. The 2006 Census of Population in Ireland reported detailed small area population statistics for 3400 electoral divisions (EDs). For each ED, this includes the number of households with and without broadband services. In addition, there are a wide range of socioeconomic indicators such as the prevalence of each social class, level of educational attainment, age, employment status and sector, type of accommodation, PC ownership, etc.

The second dataset contains geographical panel data from 2001 to 2006 on 1060 fixed line local exchange areas in Ireland and the date at which each was enabled for ADSL services (for those that were enabled in the period).[1] These two datasets have been combined using geographical information system software (ArcGIS 10) to impute the average time since ADSL services were enabled for customers in each ED.

I use regression analysis to explain the penetration of broadband at ED level in 2006, as a function of ED population characteristics, the average distance of residences from their local exchange (a proxy for quality of service) and the average time elapsed since ADSL was made available to households in each ED.

As well as broadband availability affecting the scope for adoption of services, it is likely that the expected level of adoption affects the order in which areas are enabled. This simultaneity between supply and demand factors is allowed for using the average number of residences served by the local exchanges in each area as an instrument for identifying the time since enabling, because it affects the supply side (via economies of scale in supply of ADSL) without having any obvious effect on household demand.

[1] ADSL refers to “asynchronous digital subscriber line”, a technology and set of associated standards that permit high speed digital communications to be carried over copper telephony circuits.

The next section of the article refers to some of the extensive past research on residential broadband adoption as a source of hypotheses about what factors affect broadband demand and supply. Section III describes the modelling approach, and Section IV discusses the data used. Section V describes the regression results and Section VI provides some conclusions.

2. Previous research on residential broadband adoption

A growing body of literature exists on the determinants of residential broadband demand and supply. Much of this work relies on discrete choice modelling of household data in a particular market, as in Rappoport *et al.* (2003). Another approach is to use cross-country data. For example, Billon *et al.* (2009) presents a cross country study of the determinants of ICT[2] diffusion using data from 142 low, middle and high income countries in 2004. Survey data form the main source of information about how household competencies and attitudes affect use of broadband services (e.g. Savage and Waldman (2005, 2009)). Most studies using these approaches focus on the determinants of demand, without explicitly modelling supply factors.

In this article I model demand and supply of broadband together. Glass and Stefanova (2010) and Prieger and Hu (2008) are recent examples of this approach. An important advantage of these models is that they allow for the conditionality of broadband demand on local provision of service.

Existing studies identify a wide variety of factors that influence residential broadband demand and supply. Significant influences on demand include prices, reliability and quality of service, as well as a range of customer characteristics including income, age, education and technical ability. On the supply side, perhaps the most significant factor is urban/rural location. Population density more generally and the degree of competition in the market are also highlighted in the literature. The typical findings as to direction of effects are outlined below.

Household income is normally found to be a significant positive contributor to the rate of broadband adoption. The price of services, not surprisingly, tends to have a negative effect. Reliability and quality of service are less studied, but would be expected to increase adoption; for example, Prieger and Hu (2008) find a negative association between distance from the local exchange and adoption rates. They interpret this as a quality effect, as data speeds feasible with ADSL tend to fall with increasing line length. However, Glass and Stefanova (2010) report no significant effect between mean distance to from exchange to customer and the decision to offer DSL service.

Education is generally found to have a positive effect on broadband adoption, as in Rappoport *et al.* (2003), Savage and Waldman (2005), Billon *et al.* (2009) for ICT generally, and ComReg (2009) for broadband in Ireland specifically. However, there are rare

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exceptions (e.g. some of the models in Prieger and Hu (2008) suggest that college graduates have lower broadband demand). Savage and Waldman (2009) emphasize the importance of technical ability as a positive influence on broadband access and use, as opposed to more general measures of educational attainment. In the context of Ireland, DCMNR (2006) also finds that the availability of technical skills in a household increases the uptake of broadband.

The international findings on the effect of age on broadband demand are somewhat more varied. For example, Rappoport *et al.* (2003) and Prieger and Hu (2008) show results from several models in which ADSL adoption is negatively associated with age. In contrast, Billon *et al.* (2009) find that in developing countries population age has a positive effect on ICT adoption. However, for developed countries it seems clear that the oldest age groups are less prone to adopt broadband than the rest of the population.

In common with earlier fixed line communications technologies, the 'last mile' of copper-based and fibre-based broadband networks is generally understood to exhibit strong economies of density. Forfás (2010), from the viewpoint of an Irish development agency, supports the view that investment in broadband infrastructure is crucially determined by population density and urbanization. Their work highlights Ireland's weakness on these metrics, with a combination of a high proportion of people living in rural areas (39%) and a low population density of 62 inhabitants per square kilometre. The evidence on this is not entirely one-sided, however: Whitacre and Mills (2007) use U.S. population survey data from 2000 to 2003 to examine the high speed access divide between rural and urban areas. They find that differences in education and income between rural and urban areas account for the divide and not infrastructure *per se*.

Finally, concerning the effect of time since a local exchange was enabled on broadband adoption, Prieger and Hu (2008) find a weak, but positive and highly significant effect, using US data.

There are fairly consistent messages from the literature concerning the factors that incline residential customers to take up broadband. Past research typically identified price (negative), quality (positive), education (positive), technical skills (positive), competition (positive) and age (negative) as the main factors driving broadband demand. Population density or (related to it) rural/urban location are the most frequently cited supply factors, with higher density normally associated with increased broadband availability.

3. Modelling approach

This section describes the model and estimation method used in the article.

Theoretical model

The theoretical model behind this analysis is straightforward. I assume that a household's potential utility from adopting broadband services is a function of certain socioeconomic characteristics. This is in line with the literature. However, in an extension to the usual approach, I allow for the possibility there is some lag between the service becoming available to a given household and the decision to adopt. There are many possible reasons for such a lag (e.g. network externalities, imperfect information, behavioural biases). I assume here that there is only one provider of broadband network access, which is a reasonable simplification for ADSL services in Ireland during the period being studied. Of course, both demand and supply choices might also be influenced by the presence of other technologies, particularly fixed wireless and cable-based services, that were being introduced during this period. Since there is little public information on the rollout and take-up pattern for these services during the period, the best I can do is carry out a sensitivity test using available data.

The household will adopt broadband if its expected utility is high enough, but obviously only if broadband is available to it. On the supply side, offering broadband services in a local area requires investment, for example installation of modems in local exchanges or wireless base stations. Local areas are only enabled for broadband when the expected stream of future profits from doing so becomes positive. The cost of supplying broadband is assumed to exhibit economies of density, so assuming demand rises over time, more densely populated areas will be enabled first, *ceteris paribus*.

The remainder of this section sets out the model in more formal terms. The demand model can be summarized thus:[3]

$B_{ijt} = f\left(\mathbf{X}_i, P_t, S_t, t - t_j^f\right)$ for each household *i* in area *j* at time *t* (1)

where B is a 1/0 indicator of whether broadband services are taken up, $\mathbf{X}$ is a vector of socioeconomic characteristics, P is the geographically averaged unit price, S captures the quality of service and content that is available to broadband customers. The quality of content may be growing over time but is assumed to be uniform across areas at any given time, and t_j^f is the earliest time period that broadband services were enabled in the household's area. A household's propensity to adopt broadband should be negatively associated with the price and positively associated with its quality and the time elapsed since enabling.

As the available data (discussed in the next section) are averages for geographical areas, the demand function can be expressed as:

$$\frac{\sum_{i=1}^{N_j} B_{ijt}}{N_j} = g\left(\mathbf{V}_j, P_t, S_t, t - t_j^f\right) \qquad (2)$$

where N is the number of households in the area, $\mathbf{V}$ is a matrix containing the shares of each socioeconomic characteristic in the population of the area and g is a function. When I come to estimate this function econometrically, most price and quality effects will form part of the constant, since they are assumed not to vary across areas in a given period.

[3] This is essentially the demand model in Taylor (1994), Ch.2, expressed with a spatial dimension appropriate to the data used in this study.

However, I will be able to control for the average distance of residential addresses from the local exchange in each area, which should be correlated with the average quality of xDSL service in the area, as per Prieger and Hu (2008).

The choice as to whether to enable broadband in an area can be expressed as:

$$E_{jt} = 1 \text{ if } \sum_{k=t}^{\infty} h\left(\sum_{i=1}^{N_j} B_{ijk}, P_k, C_j\right)(1+d)^{-(k-t)} > 0 \qquad (3)$$

$$E_{jt} = 0 \text{ otherwise}$$

where E is a 1/0 indicator of whether broadband services are enabled in the area, k is an index of future time periods, C is the relative unit cost of supplying broadband in the area, d is a discount rate and h is a function. The absolute average cost of supplying broadband will vary over time, but I assume that access regulation is applied that imposes a fixed relationship between the average cost and price charged, so the cost need not enter the model separately.[4] The choice of enabling an exchange should be positively associated with price and demand, but negatively associated with the relative cost of supplying the area. Adoption of broadband in an area will obviously be affected by whether the area has been enabled for ADSL service, but supply will also affect demand via the time elapsed since enabling:

$$t - t_j^f = m\left(\mathbf{V}_j, \mathbf{P}, \mathbf{C}_j, \mathbf{S},\right) \qquad (4)$$

where $\mathbf{P}$, $\mathbf{S}$ and $\mathbf{C}$ are vectors of past and expected future prices, quality/content levels and relative unit costs; m is a function. The effects of $\mathbf{P}$ and $\mathbf{S}$ will fall into the constant term when this equation is estimated using cross-sectional data. I assume that $\mathbf{C}$ is inversely proportional to the number of connections to the local exchange. Equations 2 and 4 can be estimated using available data using an econometric model discussed in the next sub-section.

Econometric model

Demand and supply of access to residential broadband services are determined simultaneously. Although I am mainly interested in the demand side, estimating the demand equation in isolation would lead to endogeneity problems. Fortunately, there is a good instrument for the cost of supplying broadband in a local area: the number of residences served by each local exchange. I use this instrument to identify the supply function in a two-stage least squares regression, with the demand equation as the second stage. Demand is thus estimated conditional on supply conditions.

First stage (supply) regression – Equation 4 above. The dependent variable in the first stage regression is the average time (in years) since ADSL was enabled in the local exchanges to which addresses in each ED are connected. Note that this variable has a

[4] The incumbent operator's supply of broadband access services was subject to wholesale price control and other regulatory measures by Ireland's Commission for Communications Regulation (ComReg) throughout this period; see ComReg (2010a and 2010b).

lower bound of zero. To facilitate estimation, the average time variable is transformed to the [0,1] interval before estimation by dividing each observation by the maximum value in the sample (given in Table 2 below). I then transform the predicted values back into years before including them in the second stage regression to make interpretation of the second stage results more straightforward.

As a proxy for the varying costs of supplying ADSL services across EDs, I include the level and squared values of the average number of residential addresses per exchange. Since there are fixed costs of ADSL supply at exchange level, total costs should be inversely associated with the number of subscribers served by an exchange, and they might have a positive association with the square of subscriber density (implying positive but diminishing economies of density). No data were available on other factors that might affect the local cost of enabling exchanges, such as the cost of additional backhaul.

All other explanatory variables employed in the demand model are also included in the first stage regression. These variables are discussed in more detail below.

Second stage (demand) regression – Equation 2 above. The dependent variable in the second stage regression is the share of addresses in each ED that had obtained access to broadband services as of 23 April 2006. This is based on self-reported census data, so it is not possible to provide a strict definition of what is included within the term "broadband" in this article.

The predicted time since enabling of ADSL in each ED, as estimated in the first stage regression, is included as a regressor here. The squared value of this variable is also included to allow for the possibility of a non-linear time effect. Prices of residential ADSL services are geographically uniform across the sample, so own-price terms are not included in the regressions.

Prices of substitutes such as wireless or cable broadband services tended also to be offered on a geographically averaged basis, but there is no publicly available information on these prices or on the geographical rollout of alternative infrastructures over time in Ireland. Such services made up about a quarter of broadband subscriptions in mid 2006. This obviously gives rise to potential for omitted variable bias. However, there is scope to carry out sensitivity test on the effect of omitting alternative providers. The models can be re-run including the share of addresses in each ED that were within the footprint of fixed wireless services in 2008.

The average quality of ADSL in an area, proxied by the average distance of residences from their local exchange, should have a positive association with broadband penetration.

Finally, a large number of demand-shifter variables are included, based on EDs' socio-economic characteristics. Details are provided in the next section. Previous research suggests that there should be significant associations between residential broadband demand and education (positive), age (negative), income (positive), social class (positive, as a proxy for long run income and assets) and PC ownership (positive). In addition, one might expect to see positive effects from the shares of people in an area working from home or born abroad (with the latter serving as a proxy for likely demand for long-distance communications). Finally, we include the share of persons in each area who speak Irish at least once per day outside a school context. Since more internet content is in English than in Irish, one might expect a preference for speaking Irish to have a negative association with demand for broadband services.

Estimation method

The dependent variables in both of the regressions are fractional (i.e. they fall in the closed interval [0,1]). OLS suffers from well-known shortcomings when applied to such data. Since many observations take a value of 0 and some are equal to 1, the option of simply applying a logistic transformation to these variables and then using OLS is not available. I therefore use the GLM quasi-likelihood estimator introduced in Papke and Wooldridge (1996) (hereafter referred to as 'fractional logit').[5]

Because these regressions are estimated on cell means, I weight each ED-level observation by the population in the ED to adjust for the unequal variances across cells.

When reporting the results, the focus is on marginal effects (and their associated standard errors). The marginal effect of each explanatory variable is evaluated with all variables set to their mean values. For completeness, the fractional logit regression coefficients and standard errors are reported in Annex A.

4. Data employed

The article draws upon two main sources of data for modelling Irish residential broadband adoption. First, local average broadband take-up and socioeconomic characteristics are taken from the Central Statistics Office Census Small Area Population Statistics (SAPS). These data are at electoral division (ED) level, covering 3392 areas.[6] Most EDs in the country are included in the analysis, and they average 20.6 square kilometres in size and 1240 in population. The SAPS dataset provides a snapshot of the position as at 23 April 2006 (the day of the most recent Irish census).

The second main source is panel data on ADSL availability in 1060 local exchange areas from 2001-2006. This dataset was provided by the main Irish fixed line carrier eircom, on foot of a request from the Commission for Communications Regulation. I assume that ADSL was available in an area from the date the local exchange was enabled. More detail is given below on how these data were assembled.

I also use data on average disposable income per capita at county level, published by the CSO. ED-level household income data would have been preferable, but this proxy is the

[5] Estimation was carried out in Stata 11, using the glm command with the following switches: family(binomial) link(logit) robust.

[6] A small number of EDs were omitted or amalgamated to allow matching of data sources. Details are available on request from the author.

best currently available. Table 1 below summarizes the variables drawn from each of these sources.

Table 1: Variable descriptions by source

Variable	Description
Exchange characteristics and eircom ADSL rollout by local exchange area, 2001-2006, mapped to EDs using the An Post Geodirectory	
Average years since ADSL was enabled	Average time since ADSL was enabled for residential addresses in each ED
Average distance from local exchange	Average Euclidean distance of residential addresses from local exchange in each ED
Average addresses per local exchange	Average number of residential addresses in the local exchange areas that overlap with each ED
Census Small Area Population Statistics, 2006, CSO	
Broadband access	Share of ED households with broadband internet access
PC ownership	Share of ED households with a personal computer
Accommodation type	Share of ED households residing in each of five accommodation types
Household composition	Share of ED households in each of five composition groupings
Highest level of education completed	Share of ED population aged 15 and older in each of seven categories for highest level of education completed
Principal economic status	Share of ED population aged 15 and older in each of eight economic status groupings
Age group	Share of ED population in each of five age bands
Industry	Share of ED working population in each of eight industry groupings
Social Class	Share of ED household reference persons in each of six social class groupings
Irish speakers	Share of ED population over 3 years old who speak Irish at least daily (outside school)
Foreign born	Share of ED population born outside Ireland
Persons working from home	Share of ED working population that works mainly from home
Persons still receiving education	Share of ED population aged 15 and older still in education
Population density	Population of ED in 2006 divided by area (in Km^2)
County Incomes and Regional GDP, 2006, CSO, published 24 February 2009	
Average disposable income per capita (county level)	Average disposable income per capita (€) in 2006 for county in which each ED is located in the sample

GIS analysis was required to map data on ADSL availability and wireless broadband coverage to EDs. This was done by identifying the local exchange area in which every residential address in Ireland was located, using a digital map provided by eircom. From this it was straightforward to calculate the Euclidean distance of each residential property from its local exchange and the average number of residences in each local exchange area. These were then averaged within EDs to give the average distance from local exchange and addresses per local exchange variables.

I then calculated the time since ADSL was made available for each address based on the ADSL availability date of the relevant local exchange. These times were calculated from the date of enabling of each local exchange to the date of the census: 23 April 2006. Addresses in non-enabled zones were assigned a zero duration since enabling. Finally, I calculated the average time since ADSL enabling for all addresses in each ED. An animated map showing the geographical pattern of ADSL deployment in Ireland from 2001-2008 is shown here. [Please put a hyperlink to the animation of broadband rollout on the word 'here'. In the print version, please replace "shown here" with "available at http:\\www….]

Descriptive statistics for the variables used in the article are shown in Table 2.

Table 2: Summary statistics (individual observations are at electoral division level, 3392 observations)

Variable description	Variable name	Mean	Std Dev	Min.	Max.
Dependent variables					
Average years since ADSL enabled	*AvgTimeSinceADSL*	1.07	1.45	0	4.82
Broadband access	*BroadbandShare*	0.106	0.0980	0	0.614
PC ownership					
Yes	*PCOwnerYes*	0.541	0.0992	0.151	0.878
No	*PCOwnerNo*	0.439	0.0972	0.108	0.818
Not stated	*PCOwnerNS*	0.0198	0.0175	0	0.176
Accommodation type					
House	*AccHouse*	0.924	0.113	0.0244	1.00
Flat/apartment	*AccFlat*	0.0443	0.103	0	0.921
Bedsit[7]	*AccBedsit*	0.00285	0.0104	0	0.162
Caravan/Mobile home	*AccOther*	0.00902	0.0127	0	0.158
Not stated	*AccNS*	0.0195	0.0175	0	0.167
Household composition					
Single person	*CompSingle*	0.224	0.0681	0.0513	0.633
Couple	*CompCouple*	0.183	0.0400	0.0286	0.366
Single & children	*CompSingle&k*	0.390	0.0960	0.0137	0.677
Couple & children	*CompCouple&k*	0.0925	0.0369	0	0.433
Other family	*CompOthFam*	0.0598	0.0243	0	0.250
Other non-related	*CompOtherNR*	0.0497	0.0458	0	0.490
Highest level of education completed					
None	*EduNone*	0.00532	0.0086	0	0.220
Primary	*EduPrimary*	0.212	0.0807	0.0155	0.581
Lower Secondary	*EduLwrSec*	0.223	0.0512	0.0263	0.383
Upper Secondary	*EduHighrSec*	0.378	0.0612	0.131	0.578
Primary Degree	*EduDegree*	0.0932	0.0497	0	0.383
Postgraduate	*EduPostgrad*	0.0492	0.0337	0	0.255
Not stated	*EduNS*	0.0393	0.0340	0	0.377
Principal economic status					
At work	*EconWork*	0.558	0.0648	0.205	0.763
Looking for first regular job	*EconLk1stJob*	0.00659	0.006	0	0.0530

[7] A bedsit is a small flat akin to a studio, normally including a single bedroom/sitting room. Limited cooking facilities are sometimes available, but the bathroom and lavatory are usually shared.

Variable description	Variable name	Mean	Std Dev	Min.	Max.
Unemployed	*EconUnemp*	0.0379	0.0232	0	0.247
Student	*EconStudent*	0.0977	0.0356	0.0163	0.679
Looking after home/family	*EconHome*	0.133	0.0307	0.0269	0.268
Retired	*EconRetired*	0.123	0.0402	0.0086	0.357
Unable to work due to sickness/disability	*EconDisabled*	0.0412	0.0213	0	0.256
Other	*EconOther*	0.00321	0.0068	0	0.278
Age group					
0 -14 years	*Age0-14*	0.208	0.0447	0.0076	0.389
15 – 24 years	*Age15-24*	0.136	0.0370	0.0417	0.607
25 – 44 years	*Age25-44*	0.286	0.0521	0.137	0.551
45 – 64 years	*Age45-64*	0.241	0.0429	0.0697	0.409
65+ years	*Age65+*	0.129	0.0438	0.0079	0.372
Industry (of those in employment)					
Agriculture, Forestry, Fishing	*IndAgric*	0.112	0.0813	0	0.517
Building & Construction	*IndBuilding*	0.134	0.0482	0.0126	0.396
Manufacturing	*IndManufac*	0.141	0.0525	0	0.405
Commerce & Trade	*IndCommerce*	0.215	0.0694	0	0.507
Transport & Communications	*IndTransComms*	0.0454	0.0228	0	0.235
Public Admin	*IndPublic*	0.0473	0.0245	0	0.314
Professional Services	*IndProfess*	0.164	0.0432	0.0375	0.401
Other	*IndOther*	0.141	0.0643	0	0.573
Social Class (of household reference person)					
ABC: Employers & managers; Higher professional; Lower professional	*SocialClassABC*	0.246	0.103	0.0212	0.704
D: Non-manual	*SocialClassD*	0.124	0.0478	0	0.307
EF: Manual skilled; Semi-skilled	*SocialClassEF*	0.194	0.0581	0	0.423
GJ: Unskilled; Agricultural workers	*SocialClassGJ*	0.0584	0.0304	0	0.267
HI: Farmers; Own account workers	*SocialClassHI*	0.203	0.114	0	0.556
Z: Others gainfully occupied & unknown	*SocialClassZ*	0.175	0.0733	0	0.600
Irish speakers	*IrishSpeakers*	0.0147	0.0464	0	0.548
Foreign born	*ForeignBorn*	0.120	0.066	0	0.598
Persons working from home	*HomeWorkers*	0.055	0.0358	0	0.245
Persons over age 15 still receiving education	*PersStillEducat*	0.109	0.0385	0.0261	0.660
Disposable Income per capita (county level)	*AvgIncome*	19 800	1520	17 300	23 200
Average distance from	*ExchangeDist*	2950	1680	140	13

Variable description	Variable name	Mean	Std Dev	Min.	Max.
local exchange					400
Average addresses per local exchange	*ExchangeSize*	3320	4770	107	27 200

5. Results

Marginal effects from the regressions are set out in Table 3 (first stage; supply) and Table 4 (second stage; demand) overleaf. The regression coefficients are included in the Annex.

Time pattern of reaction to local ADSL supply

On average, an extra year since local enabling of ADSL is associated with an increase of 5.2 percentage points in average ED-level broadband take-up (Table 4, marginal effect of *AvgTimeSinceADSLhat* and its squared value) for the EDs in our sample. This effect is significant at the 1% level, and it is sizeable when compared to the 10.6% average ED-level broadband penetration rate in the sample. In other words, I find evidence that areas enabled for longer had higher broadband adoption. Areas that were not supplied with ADSL in the sample period report an average broadband penetration rate of 5.3%, which must be mainly cable and fixed wireless services.

Table 3: First stage regression marginal effects: dependent variable: *AvgTimeSinceADSL* transformed to [0,1]; 3392 observations

Variables	MFX	Robust S.E.
Ln(ExchangeDist)	-0.0222	0.0144
PCOwnerYes	[REF]	
PCOwnerNo	0.586	0.188***
PCOwnerNS	-0.815	0.722
SocialClassABC	[REF]	
SocialClassD	-0.0755	0.312
SocialClassEF	-0.0939	0.259
SocialClassGJ	-1.16	0.424***
SocialClassHI	-0.534	0.253**
SocialClassZ	-0.627	0.229***
EconWork	[REF]	
EconLk1stJob	-0.418	1.44
EconUnemp	-0.819	0.492*
EconStudent	1.28	0.563**
EconHome	-0.890	0.426**
EconRetired	-0.146	0.494
EconDisabled	-0.623	0.457
EconOther	-0.0187	0.458
AccHouse	[REF]	
AccFlat	0.150	0.102
AccBedsit	2.41	0.543***
AccOther	0.519	0.622
AccNS	1.09	0.679
Age0-14	-0.566	0.463
Age15-24	-1.06	0.531**
Age25-44	[REF]	
Age45-64	0.493	0.290*
Age65+	0.350	0.515

Variables	MFX	Robust S.E.
IndAgric	-1.05	0.335***
IndBuilding	-0.813	0.279***
IndManufac	-1.32	0.231***
IndCommerce	[REF]	
IndTransComms	-0.866	0.461*
IndPublic	-0.439	0.338
IndProfess	-1.06	0.238***
IndOther	-0.624	0.24***
CompSingle	-0.753	0.219***
CompCouple	-0.435	0.272
CompSingle&k	0.724	0.297**
CompCouple&k	[REF]	
CompOthFam	0.0869	0.396
CompOtherNR	-0.0498	0.323
EduNone	0.508	0.712
EduPrimary	-0.108	0.207
EduLwrSec	-0.497	0.263*
EduHighrSec	[REF]	
EduDegree	-0.529	0.383
EduPostgrad	-1.06	0.493**
EduNS	0.197	0.291
IrishSpeakers	0.238	0.161
ForeignBorn	0.568	0.147***
PersStillEducat	-0.257	0.546
HomeWorkers	-1.32	0.420***
Ln(AvgIncome)	0.805	0.130***
ExchangeSize	0.0000904	0***
ExchangeSize^2	-2.32E-09	0***

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Data sources: see Table 1 above.*

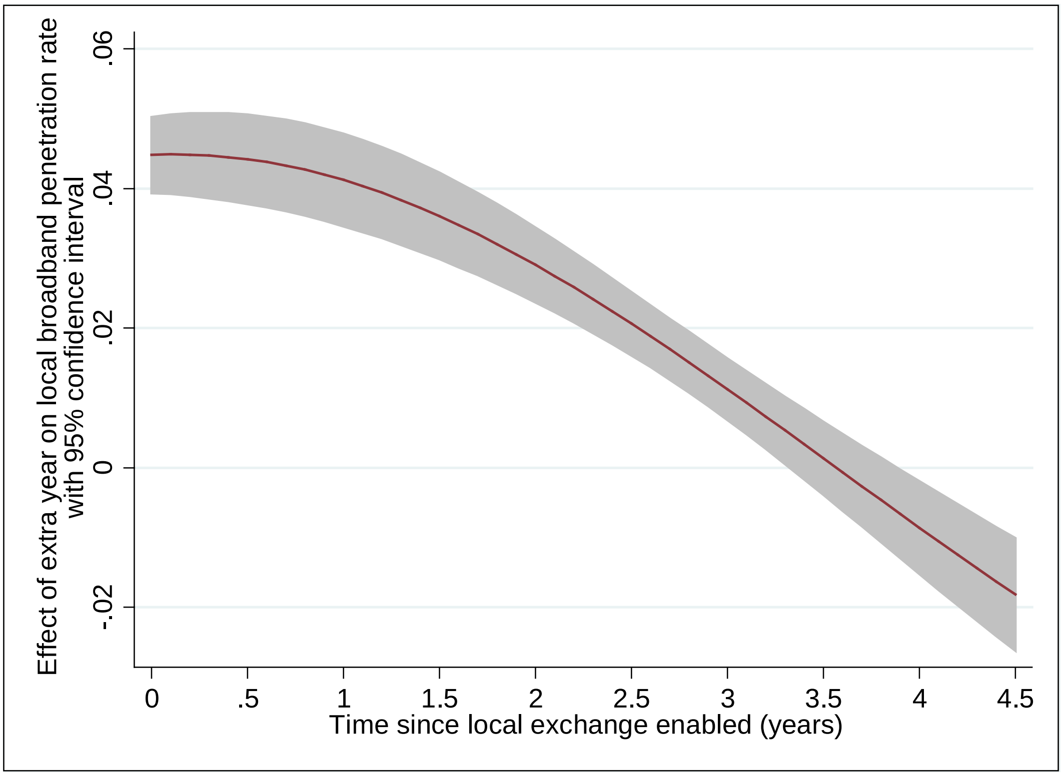
Table 4: Second stage regression marginal effects: dependent variable: *BroadbandShare*; 3392 observations

Variables	MFX	Robust S.E.	Variables	MFX	Robust S.E.
AvgTimeSinceADSLhat	0.0610	0.00571***	*IndAgric*	-0.250	0.0783***
AvgTimeSinceADSLhat^2	-0.00855	0.000960***	*IndBuilding*	-0.149	0.0541***
Ln(ExchangeDist)	-0.0200	0.00252***	*IndManufac*	-0.0362	0.0538
PCOwnerYes	[REF]		*IndCommerce*	[REF]	
PCOwnerNo	-0.501	0.0380***	*IndTransComms*	-0.182	0.0794**
PCOwnerNS	-0.504	0.0927***	*IndPublic*	-0.160	0.0701**
SocialClassABC	[REF]		*IndProfess*	-0.241	0.047***
SocialClassD	0.0466	0.0590	*IndOther*	-0.142	0.0472***
SocialClassEF	-0.0199	0.0559	*CompSingle*	0.146	0.0427***
SocialClassGJ	-0.342	0.0791***	*CompCouple*	0.0722	0.0502
SocialClassHI	-0.182	0.0567***	*CompSingle&k*	0.277	0.0585***
SocialClassZ	0.0379	0.0434	*CompCouple&k*	[REF]	
EconWork	[REF]		*CompOthFam*	0.261	0.0756***
EconLk1stJob	0.665	0.287**	*CompOtherNR*	0.158	0.0545***
EconUnemp	0.0181	0.0830	*EduNone*	-0.0356	0.140
EconStudent	-0.121	0.100	*EduPrimary*	0.0313	0.0386
EconHome	0.0642	0.0815	*EduLwrSec*	-0.187	0.0563***
EconRetired	0.0515	0.0999	*EduHighrSec*	[REF]	
EconDisabled	0.126	0.0909	*EduDegree*	0.0331	0.0769
EconOther	0.0650	0.116	*EduPostgrad*	-0.0269	0.0970
AccHouse	[REF]		*EduNS*	-0.0201	0.0466
AccFlat	-0.0298	0.0160*	*IrishSpeakers*	0.0384	0.0365
AccBedsit	-0.264	0.0791***	*ForeignBorn*	-0.00381	0.0245
AccOther	-0.456	0.139***	*PersStillEducat*	0.114	0.111
AccNS	-0.0289	0.109	*HomeWorkers*	-0.0994	0.0731
Age0-14	0.0303	0.0861	*Ln(AvgIncome)*	0.117	0.0225***
Age15-24	0.121	0.103			
Age25-44	[REF]				
Age45-64	0.0709	0.0555			
Age65+	-0.0149	0.102			

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Data sources: see Table 1 above.*

The impact of additional time since enabling itself varies over time. The first year since local enabling provides more than a 4 percentage point increase in local broadband adoption, and the effect declines thereafter. This is illustrated in Figure 1 below. The results imply that the boost to growth rates following local enabling has run its course after 3.5 years on average.

Figure 1: Marginal effect of an extra year of ADSL availability in an ED on the household broadband penetration rate with varying lags; shaded area shows 95% confidence interval



I now turn to other determinants of broadband demand and ADSL supply, starting with demand as this is the main focus of the article before turning to the supply results.

Demand equation

The results for the second stage (demand) equation are broadly in line with expectations. The average distance of households from the local exchange has a weak but strongly significant negative association with penetration, which makes sense since it is a proxy for service quality.

Areas where household reference persons are of lower social class or have only a lower secondary level education tend to have lower broadband penetration. Also as expected, areas where fewer households have PCs (or do not state whether they have them) are less prone to take up broadband and persons living in houses rather than other types of accommodation are more likely to take up broadband. The share of people in an ED seeking their first jobs has a strong positive association with broadband take-up, which seems reasonable.

Sector of employment has a complex set of effects. Commerce is the reference category and manufacturing does not give significantly different results. Employment in agriculture and the professions show the strongest negative associations (about 24-25% lower), while, the public sector, building, transport and communications and 'other' are about 15-18% lower.

The log of disposable income shows a modest but highly significant positive effect: for every 10% increase in disposable income, the model implies a 1.2 percentage point increase in local broadband adoption.

There is no significant effect for persons working from home, Irish speakers, those born abroad or persons over age 15 still in education. Couples with children show a lower level of broadband penetration than most other family types.

Supply equation

The first stage (supply) equation was estimated principally to correct the demand equation for possible endogeneity bias. Nevertheless, its results may be of interest in their own right. As expected, ADSL enabling takes place earlier in areas with a higher social class profile, more people in employment or students, a high proportion of commercial sector employees, foreign born persons and higher incomes. It takes place later in areas with larger proportions of single person households.

The number of residences in an exchange area has the expected positive sign in levels and negative sign in the squared term, consistent with positive but diminishing economies of density. Both terms are highly significant. The coefficients imply an expectation that economies of density for ADSL technology are maximized at about 19 500 residential addresses in an exchange area.

Other terms on the supply side are less easy to interpret. There is some evidence of an unexpected negative association between areas with a high proportion of postgraduate degree holders and ADSL supply. ADSL seems to be enabled sooner in areas with low PC ownership or higher proportions of 15-24 year olds, but later in areas with a larger number of people working from home.

Sensitivity test

As noted earlier, no data are available on the rollout of alternative broadband infrastructures such as cable and fixed wireless over time in Ireland. To test whether omitting this information is likely to have significantly affected the modelling results, I re-ran the regressions with an added explanatory variable: the share of addresses in each ED that were within the footprint of fixed wireless services in 2008. The wireless coverage variable was not significant in either regression and it did not affect the sign or significance level of any other explanatory variable.

6. Conclusions

Even in jurisdictions where matched data are not collected on demand and supply of broadband services, it may be possible to estimate market parameters by linking other spatially-coded datasets. This article reports results from a two-stage model of broadband demand and ADSL supply, primarily using small area data from the Census of Population and GIS data from the incumbent fixed line operator on the location of local exchanges and the ADSL rollout over time.

It takes time for households in an area to take up broadband services once they are offered, even apart from any tendency for broadband demand to rise over time across the whole population.

The first year since local enabling provides more than a 4 percentage point increase in local broadband adoption, and the effect declines thereafter. The boost to growth rates following local enabling has run its course after 3.5 years on average. Commercial suppliers planning to roll out services and public bodies contemplating subsidies or universal service provisions for extensions to broadband network should take the expected time profile of adoption into account.

The main findings on the socioeconomic determinants of broadband supply and demand are summarised in Table 5 below. These results are broadly in line with previous research in other countries. This suggests that the strategy of using geographically linked datasets for demand and supply can allow one to assemble a reasonable model of the market.

Table 5: Summary of main results concerning socioeconomic influences on broadband demand and supply (+ positive effect, - negative, blank insignificant)

Influences	Demand	Supply
Distance to exchange (proxy for lower quality of service)	-	
Higher disposable income	+	+
PC ownership	+	-
Higher social class	+	+
Living in a house rather than other sorts of accommodation	+	
Commercial sector employment	+	+
Highest education level lower secondary	-	
Share of population aged 15-24		-
Couples with children relative to other family types	-	+/-
Home workers		-
Foreign born persons		+
Residential addresses per exchange	*not included*	+

Source: analysis of Tables 3 and 4 above.

This analysis benefitted from availability of geographically matched data on the supply of ADSL and socioeconomic data including take-up of broadband. Controlling for variations in supply is important when estimating the determinants of demand, and this is not always done in the literature due to data limitations.

However, there are also some shortcomings in the available data. Panel data at household level would have been preferable to cross-sectional data on areas (although it was possible to include the time dimension of ADSL availability). It would be interesting to measure the effects discussed here in a jurisdiction where household level panel data on actual (as opposed to perceived) availability and use of broadband services could be obtained.

If data were available on the geographical rollout of fixed wireless and cable broadband over time, it would be useful to examine how these infrastructures interacted with ADSL on both the supply and demand sides (at least in jurisdictions where competing infrastructures serve a significant share of the market).

There is also no information on household incomes at small area level in Ireland, so county-level income data were included instead. However, small area data on social class and educational attainment should have captured much of the income variation across EDs.

Acknowledgements

The author would like to thank Alice Casey and Niamh Crilly for research assistance and Patricia Dowling and John Lysaght for help in obtaining data. Laura Malaguzzi Valeri, Paul Walsh and Paul Gorecki provided helpful comments on drafts, and I am grateful for comments received at the 2010 European Regional Conference of the International Telecommunications Society and at an ESRI seminar. 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. The usual disclaimer applies.

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Annex 1 – Regression results: fractional logit coefficients

Table 6: First stage regression: dependent variable: *AvgTimeSinceADSL* transformed to [0,1]; fractional logit coefficients

Variables	Coef.	Robust S.E.
Ln(ExchangeDist)	-0.0892	0.0578
PCOwnerYes	[REF]	
PCOwnerNo	2.35	0.757***
PCOwnerNS	-3.27	2.90
SocialClassABC	[REF]	
SocialClassD	-0.303	1.25
SocialClassEF	-0.377	1.04
SocialClassGJ	-4.67	1.70***
SocialClassHI	-2.14	1.02**
SocialClassZ	-2.52	0.919***
EconWork	[REF]	
EconLk1stJob	-1.68	5.77
EconUnemp	-3.29	1.98*
EconStudent	5.14	2.26**
EconHome	-3.57	1.71**
EconRetired	-0.587	1.98
EconDisabled	-2.50	1.84
EconOther	-0.0750	1.84
AccHouse	[REF]	
AccFlat	0.604	0.411
AccBedsit	9.68	2.18***
AccOther	2.08	2.50
AccNS	4.37	2.73
Age0-14	-2.27	1.86
Age15-24	-4.24	2.13**
Age25-44	[REF]	
Age45-64	1.98	1.16*
Age65+	1.40	2.07
IndAgric	-4.23	1.35***
IndBuilding	-3.27	1.12***
IndManufac	-5.29	0.929***
IndCommerce	[REF]	
IndTransComms	-3.48	1.85*
IndPublic	-1.76	1.36
IndProfess	-4.25	0.954***
IndOther	-2.51	0.965***
CompSingle	-3.02	0.88***
CompCouple	-1.75	1.09
CompSingle&k	2.91	1.19**
CompCouple&k	[REF]	
CompOthFam	0.349	1.59
CompOtherNR	-0.200	1.30
EduNone	2.04	2.86
EduPrimary	-0.432	0.830
EduLwrSec	-2.00	1.06*
EduHighrSec	[REF]	
EduDegree	-2.12	1.54
EduPostgrad	-4.26	1.98**
EduNS	0.791	1.17
IrishSpeakers	0.954	0.645
ForeignBorn	2.28	0.589***
PersStillEducat	-1.03	2.19
HomeWorkers	-5.32	1.68***
Ln(AvgIncome)	3.23	0.522***
ExchangeSize	0.000363	0.0000183***
ExchangeSize^2	-9.32E-09	6.70E-10***
Constant	-28.4	5.50***

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Data sources: see Table 1 above.*

Table7: Second stage regression: dependent variable: *BroadbandShare*; fractional logit coefficients

Variables	Coef.	Robust S.E.
AvgTimeSinceADSLhat	0.437	0.0410***
AvgTimeSinceADSLhat^2	-0.0613	0.00687***
Ln(ExchangeDist)	-0.143	0.0181***
PCOwnerYes	[REF]	
PCOwnerNo	-3.59	0.270***
PCOwnerNS	-3.61	0.664***
SocialClassABC	[REF]	
SocialClassD	0.334	0.423
SocialClassEF	-0.143	0.401
SocialClassGJ	-2.45	0.567***
SocialClassHI	-1.30	0.406***
SocialClassZ	0.272	0.311
EconWork	[REF]	
EconLk1stJob	4.77	2.06**
EconUnemp	0.130	0.595
EconStudent	-0.867	0.718
EconHome	0.460	0.584
EconRetired	0.369	0.716
EconDisabled	0.906	0.651
EconOther	0.466	0.831
AccHouse	[REF]	
AccFlat	-0.213	0.115*
AccBedsit	-1.89	0.566***
AccOther	-3.27	0.999***
AccNS	-0.207	0.783
Age0-14	0.217	0.617
Age15-24	0.866	0.737
Age25-44	[REF]	
Age45-64	0.508	0.398
Age65+	-0.107	0.733

Variables	Coef.	Robust S.E.
IndAgric	-1.79	0.561***
IndBuilding	-1.07	0.388***
IndManufac	-0.259	0.385
IndCommerce	[REF]	
IndTransComms	-1.31	0.569**
IndPublic	-1.15	0.502**
IndProfess	-1.73	0.337***
IndOther	-1.02	0.339***
CompSingle	1.05	0.306***
CompCouple	0.517	0.360
CompSingle&k	1.98	0.419***
CompCouple&k	[REF]	
CompOthFam	1.87	0.542***
CompOtherNR	1.13	0.39***
EduNone	-0.255	1.00
EduPrimary	0.225	0.276
EduLwrSec	-1.34	0.403***
EduHighrSec	[REF]	
EduDegree	0.237	0.551
EduPostgrad	-0.193	0.695
EduNS	-0.144	0.334
IrishSpeakers	0.275	0.261
ForeignBorn	-0.0273	0.176
PersStillEducat	0.816	0.798
HomeWorkers	-0.712	0.524
Ln(AvgIncome)	0.842	0.162***
Constant	-7.78	1.72***

*Note: *, ** and *** denote significant at the 10%, 5% and 1% level respectively. Data sources: see Table 1 above.*

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