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Conference Paper

Timing and determinants of local residential broadband adoption: evidence from Ireland

21st European Regional ITS Conference, Copenhagen 2010

Provided in cooperation with:
International Telecommunications Society (ITS)

21st European Regional ITS Conference
Copenhagen, 13-15 September 2010

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Timing and determinants of local residential broadband adoption: evidence from Ireland

Abstract

This paper tests whether households that are offered broadband service for the first time tend to delay in taking it up. Using cross-sectional data on broadband take-up and socioeconomic characteristics of small areas in Ireland, linked to GIS data on ADSL availability, I find that local adoption rates are positively associated with the time elapsed since service was first offered. The strength of this association increases for the first two years after local enabling of service and then decreases to zero after about five years. The paper 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. Further research will be needed to explain the mechanisms behind lags in adoption behaviour, but those evaluating investments or subsidies in broadband infrastructure should such take lags into account.

Draft revised 10 November 2010. Please do not cite or quote without permission from the author.

JEL codes: L96, D12, R22
Key words: residential broadband demand, econometric analysis, speed of adoption

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1. Introduction

Governments considering direct investments in broadband infrastructure or extension of universal service obligations to cover broadband services should take the societal costs and benefits of such interventions into account. Regulatory intervention in these markets should only be contemplated where it can address market failures such as the presence of unpriced externalities. The presumed benefits of intervention tend to include increased adoption and use of services among poorly-served areas and groups, which in turn may be associated with external benefits. However, such benefits should be weighed against the costs of intervention before any particular measure is adopted.

The research question in this paper 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. While the first part of this question is more novel, both issues are of policy relevance. 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 paper 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 3,400 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 1,060 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 a geographical information system (ArcGIS 9) 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 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 population density of each area as an instrument for identifying the time since enabling, because it affects the supply side (via economies of density in ADSL) without having any obvious effect on household demand.

The next section of the paper 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 3 describes the modelling approach, and

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[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.

Section 4 discusses the data used. Section 5 describes the regression results and Section 6 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 paper 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

[2] Information and communication technologies

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 exceptions (e.g. some of the models in Prieger and Hu (2008) suggest that college graduates have lower broadband demand). Savage and Waldman (2009) emphasise 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), 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 paper.

3.1 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. 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 impose simple proxy variables for demand and supply shifts associated with fixed wireless coverage when estimating the econometrics.

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 summarised thus:

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

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, which is assumed to grow over time and to be constant 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, the price and quality effects will form part of the constant, since they are assumed not to vary across areas in a given period.

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. 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:

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

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 population density of the area. Equations 2 and 4 can be estimated using available data using an econometric model discussed in the next sub-section.

3.2 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: population density. 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.

3.2.1. 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 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.

To allow for varying costs of supplying ADSL services across EDs, I include the level and squared value of population density. ADSL supply should have a positive association with population density, and possibly a negative one with the square of density (implying positive but diminishing economies of density). 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.

3.2.2. 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 paper.

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. As a proxy for the availability of other broadband platforms, I include the share of addresses in each ED that were within the footprint of fixed wireless services (assumed to be a substitute for ADSL) in 2008.

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. In any event, I was not able to obtain geographically detailed price information for such services, so prices of substitutes are not included either.

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.

3.3 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').[3]

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 paper 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 3,392 areas.[4] Most EDs in the country are included in the analysis, and they average 20.6 square kilometres in size and 1,240 in population. The SAPS dataset provides a snapshot of the position as at 23 April 2006 (the day of the most recent Irish census).

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

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

The second main source is panel data on ADSL availability in 1,060 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.

Other sources include GIS data on the coverage of wireless broadband services in 2008, collected by the Department of Communications, Energy and Natural Resources (DCENR), and average disposable income per capita at county level, published by the CSO. Neither of these sources is ideal; I would have preferred to use wireless coverage data for 2006 (or better still 2001-2006) and ED-level household incomes. However, these proxies are the best currently available. Table 1 below summarises the variables drawn from each of these sources.

Table 1: Variable descriptions by source

Variable	**Description**
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 (further details are given in the text below).
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)

Wireless Broadband Coverage Map, DCENR	
Wireless broadband coverage in 2008	Share of residential addresses in ED with wireless broadband coverage as of June 2008
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. 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. [In the print version, please replace "shown here" with "available at http:\\www….]

Creating the wireless broadband coverage variable was more straightforward. I identified which addresses were in coverage in 2008 according to the DCENR digital map and then calculated the share of addresses in each ED that were covered.

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

Table 2: Summary statistics (individual observations are at electoral division level, 3,392 observations)

Variable description	Variable name	Mean	Std Dev	Min.	Max.
Dependent variables					
Average years since ADSL enabled	*AvgTimeSinceADSL*	1.08	1.46	0	4.82
Broadband access	*BroadbandShare*	0.106	0.0980	0	0.614
PC ownership					

Variable description	Variable name	Mean	Std Dev	Min.	Max.
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[5]	*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*	0.0925	0.0370	0	0.433
Couple & children	*CompCouple&k*	0.390	0.0960	0.0137	0.677
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	0.00856	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*	0.557	0.0648	0.205	0.763
Looking for first regular job	*EconLk1stJob*	0.00659	0.00597	0	0.0530
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	0.0401	0.00860	0.357
Unable to work due to sickness/disability	*EconDisabled*	0.0412	0.0213	0	0.256
Other	*EconOther*	0.00321	0.00683	0	0.278
Age group					
0 -14 years	*Age0-14*	0.208	0.0447	0.00760	0.389
15 – 24 years	*Age15-24*	0.136	0.037	0.0417	0.607
25 – 44 years	*Age25-44*	0.286	0.0521	0.137	0.551

[5] 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.
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*	0.12	0.066	0	0.598
Persons working from home	*HomeWorkers*	0.0550	0.0358	0.0000	0.2450
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	1,520	17,300	23,200
Wireless broadband coverage in 2008	*WirelessCov*	0.791	0.161	0.043	1
Population density	*PopDensity*	746	2,230	0.716	32,700

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.

5.1 Time lag in effect of ADSL supply

On average, an extra year since local enabling of ADSL is associated with an increase of 6 percentage points in average ED-level broadband take-up (Table 4, marginal effect of *AvgTimeSinceADSLhat*) 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 strong evidence that areas enabled for longer had higher broadband adoption.

The impact of additional time since enabling itself varies over time. The first year since local enabling provides just under a 4 percentage point increase in local broadband adoption, the effect peaks after two years with about a 6 percentage point increase and declines thereafter. This is illustrated in Figure 1 below. The model implies that there is no further effect of time since local enabling after about five years.

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

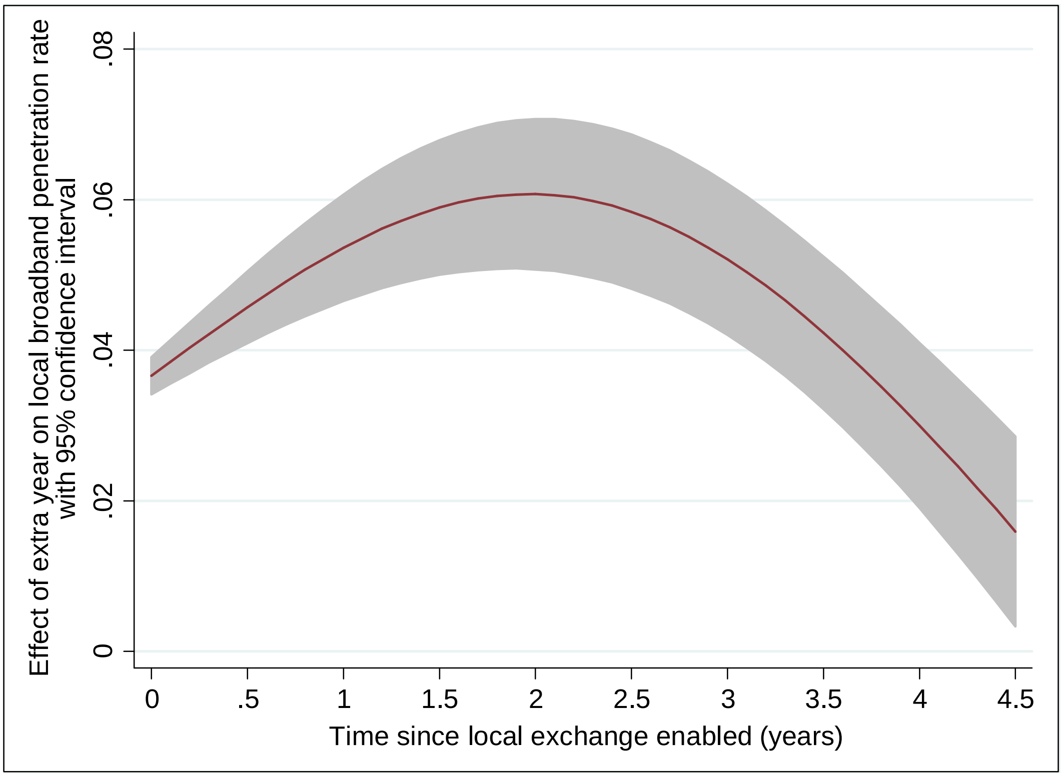

Table 3: First stage regression marginal effects: dependent variable: *AvgTimeSinceADSL* transformed to [1,0]; 3,392 observations

Variables	MFX	Robust S.E.
WirelessCov	0.105	0.0251***
PCOwnerYes	[REF]	
PCOwnerNo	-0.0795	0.0834
PCOwnerNS	0.0208	0.284
SocialClassABC	[REF]	
SocialClassD	-0.157	0.145
SocialClassEF	-0.272	0.122**
SocialClassGJ	-1.02	0.199***
SocialClassHI	-0.440	0.125***
SocialClassZ	-0.304	0.109***
EconWork	[REF]	
EconLk1stJob	0.685	0.652
EconUnemp	0.363	0.229
EconStudent	-0.135	0.262
EconHome	-0.592	0.189***
EconRetired	-0.189	0.218
EconDisabled	-0.0528	0.218
EconOther	0.336	0.261
AccHouse	[REF]	
AccFlat	0.0355	0.0516
AccBedsit	0.698	0.271***
AccOther	-0.323	0.331
AccNS	0.185	0.280
Age0-14	0.0236	0.206
Age15-24	0.0604	0.259
Age25-44	[REF]	
Age45-64	0.213	0.130
Age65+	0.550	0.235**

Variables	MFX	Robust S.E.
IndAgric	-1.07	0.164***
IndBuilding	-1.16	0.129***
IndManufac	-0.962	0.115***
IndCommerce	[REF]	
IndTransComms	-0.837	0.187***
IndPublic	-0.459	0.172***
IndProfess	-0.758	0.111***
IndOther	-0.781	0.117***
CompSingle	-0.334	0.102***
CompCouple	-0.285	0.116**
CompSingle&k	0.285	0.127**
CompCouple&k	[REF]	
CompOthFam	0.145	0.163
CompOtherNR	0.149	0.140
EduNone	0.125	0.400
EduPrimary	0.0146	0.0958
EduLwrSec	0.132	0.123
EduHighrSec	[REF]	
EduDegree	-0.433	0.194**
EduPostgrad	-0.247	0.273
EduNS	-0.0945	0.159
IrishSpeakers	0.0593	0.0754
ForeignBorn	0.256	0.0751***
PersStillEducat	0.243	0.261
HomeWorkers	-0.615	0.193***
Ln(AvgIncome)	0.391	0.0650***
PopDensity	4.32E-05	0***
PopDensity^2	-1.4E-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*; 3,392 observations

Variables	MFX	Robust S.E.
AvgTimeSinceADSLhat	0.0613	0.00417***
AvgTimeSinceADSLhat^2	-0.00609	0.000620***
WirelessCov	-0.0187	0.00539***
PCOwnerYes	[REF]	
PCOwnerNo	-0.184	0.0214***
PCOwnerNS	-0.296	0.0615***
SocialClassABC	[REF]	
SocialClassD	0.0535	0.0299*
SocialClassEF	-0.00831	0.0258
SocialClassGJ	-0.0162	0.0430
SocialClassHI	-0.0298	0.0255
SocialClassZ	0.00716	0.0232
EconWork	[REF]	
EconLk1stJob	0.300	0.153**
EconUnemp	-0.00966	0.0599
EconStudent	-0.0590	0.0570
EconHome	0.171	0.0413***
EconRetired	0.183	0.0485***
EconDisabled	0.0318	0.0504
EconOther	-0.0223	0.0599
AccHouse	[REF]	
AccFlat	-0.012	0.0106
AccBedsit	-0.299	0.0503***
AccOther	-0.162	0.0712**
AccNS	0.0240	0.0623
Age0-14	-0.0480	0.0442
Age15-24	0.0956	0.0527*
Age25-44	[REF]	
Age45-64	0.0158	0.0298
Age65+	-0.178	0.0517***

Variables	MFX	Robust S.E.
IndAgric	0.0258	0.0336
IndBuilding	0.102	0.0304***
IndManufac	0.103	0.0257***
IndCommerce	[REF]	
IndTransComms	0.0769	0.0452*
IndPublic	-0.0189	0.0365
IndProfess	-0.0155	0.0260
IndOther	0.0367	0.0277
CompSingle	0.0863	0.0243***
CompCouple	0.0571	0.0249**
CompSingle&k	0.103	0.0297***
CompCouple&k	[REF]	
CompOthFam	0.0328	0.0375
CompOtherNR	0.0167	0.0297
EduNone	-0.0367	0.0920
EduPrimary	-0.0276	0.0198
EduLwrSec	-0.105	0.0273***
EduHighrSec	[REF]	
EduDegree	0.0814	0.0402**
EduPostgrad	0.0539	0.0499
EduNS	0.0106	0.032
IrishSpeakers	0.00161	0.0213
ForeignBorn	-0.00459	0.0144
PersStillEducat	0.0705	0.0575
HomeWorkers	0.0250	0.0355
Ln(AvgIncome)	-0.0171	0.0146

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

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

5.2 Demand equation

The results for the second stage (demand) equation are broadly in line with expectations. Areas where a higher proportion of persons have relatively low levels of educational attainment or where household reference persons are of lower social class tend to have lower broadband penetration. Also as expected, areas where fewer households have PCs (or do not state whether they have them) or there are more residents over 65 are less prone to take up broadband. Accommodation type is a significant indicator in some cases, with those living in houses rather than bedsits or caravans being more likely to take up broadband.

Economic status gives some surprising results. The reference category here is people in work. The share of people in an ED seeking their first jobs has a strong positive association with broadband take-up, which seems reasonable. However, smaller but still significant positive effects are shown for the shares of retired persons and those performing home duties.

There is little pattern to the effects from sector of employment (where commerce is the reference category), with modest negative effects from agriculture, the public sector and the professions and positive effects from manufacturing and building.

There is no significant effect for household income, persons working from home, Irish speakers, those born abroad or persons over age 15 still in education. The non-result for income probably has to do with the weak proxy used (county average income). Family structure, with a reference category of families with children, shows significant positive effects for single persons, couples without children and single parent households.

The presence of wireless broadband coverage in an area has a weak but significant negative association with take-up of broadband generally. This may be a spurious association or it may be an artefact of the way I have modelled this variable; as we shall see below, wireless penetration shows a stronger positive effect in the supply equation.

5.3 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. The model shows a positive association between fixed wireless coverage and ADSL supply. This probably reflects omitted area-specific factors affecting expected take-up of both technologies rather than a causal relationship between them. As expected, ADSL enabling takes place earlier in areas with a higher social class profile and higher incomes. It takes place later in areas with larger proportions of households without children and people carrying out home duties. Population density 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 maximised at about 15,400 persons per square kilometre.

Other terms on the supply side are less easy to interpret. PC ownership and the prevalence of different levels of educational attainment are not generally significantly different from their reference categories. There is some evidence of an unexpected negative association between areas with a high proportion of degree holders and ADSL supply. ADSL seems to be enabled sooner in areas with higher proportions of over-65 year olds or those born abroad, but later in areas with a larger number of people working from home. There is a strong positive association between ADSL enabling and the proportion of people in an ED working in the commercial sector compared to all other sectors.

6. Conclusions

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. I have examined the diffusion of ADSL services in Ireland during the early 2000s, and the relative rate of broadband adoption in local areas seems to accelerate for the first two years after enabling. It then declines to zero after another three years or so.

It was not possible to cast much light on the reasons for these time effects in this paper, because there is no information at small area level on households' knowledge of or attitudes to broadband services in Ireland. The presence of local network effects (i.e. the value of access is higher if your neighbours have it too) is one possible explanation. Whatever the reason for the lags, 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. Based on these results, one would expect that initial adoption rates in a given area will be lower than the current period average for previously-enabled areas. This implies a reduction in the net present value of enabling each area, compared to a model where adoption rates are invariant to the time since enabling. However, these results also imply that low initial adoption in an area is not the final word on the area's potential. Adoption rates should be expected to accelerate for a period of years following introduction of local services.

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.

In addition, there is no publicly available information on the geographical rollout of fixed wireless and cable broadband over time in Ireland. Such services made up about a quarter of broadband subscriptions in mid 2006. However, a crude proxy for this is included in the regressions, in the form of the geographical availability of fixed wireless broadband as of 2008. 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.

This paper provides support for the empirical observation that broadband adoption increases with the time since local services are enabled, but it does not cast much light on the mechanisms behind it. That is left for future work.

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

Variables	Coef.	Robust S.E.
WirelessCov	0.800	0.193***
PCOwnerYes	[REF]	
PCOwnerNo	-0.607	0.636
PCOwnerNS	0.159	2.17
SocialClassABC	[REF]	
SocialClassD	-1.20	1.11
SocialClassEF	-2.08	0.927**
SocialClassGJ	-7.79	1.52***
SocialClassHI	-3.35	0.954***
SocialClassZ	-2.32	0.834***
EconWork	[REF]	
EconLk1stJob	5.23	4.98
EconUnemp	2.77	1.74
EconStudent	-1.03	2.00
EconHome	-4.52	1.44***
EconRetired	-1.44	1.67
EconDisabled	-0.403	1.66
EconOther	2.56	1.99
AccHouse	[REF]	
AccFlat	0.271	0.393
AccBedsit	5.32	2.07***
AccOther	-2.46	2.53
AccNS	1.41	2.14
Age0-14	0.180	1.57
Age15-24	0.461	1.98
Age25-44	[REF]	
Age45-64	1.62	0.996
Age65+	4.20	1.79**

Variables	Coef.	Robust S.E.
IndAgric	-8.14	1.26***
IndBuilding	-8.86	0.993***
IndManufac	-7.34	0.887***
IndCommerce	[REF]	
IndTransComms	-6.39	1.43***
IndPublic	-3.50	1.31***
IndProfess	-5.78	0.838***
IndOther	-5.96	0.887***
CompSingle	-2.55	0.777***
CompCouple	-2.17	0.883**
CompSingle&k	2.17	0.968**
CompCouple&k	[REF]	
CompOthFam	1.10	1.24
CompOtherNR	1.13	1.07
EduNone	0.952	3.05
EduPrimary	0.112	0.730
EduLwrSec	1.01	0.939
EduHighrSec	[REF]	
EduDegree	-3.30	1.48**
EduPostgrad	-1.89	2.09
EduNS	-0.721	1.21
IrishSpeakers	0.452	0.575
ForeignBorn	1.95	0.570***
PersStillEducat	1.85	2.00
HomeWorkers	-4.69	1.48***
Ln(AvgIncome)	2.99	0.496***
PopDensity	0.00033	3.06E-05***
PopDensity^2	-1.03E-08	1.50E-09***
Constant	-24.0	5.11***

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

Table 6: Second stage regression: dependent variable: *BroadbandShare*; fractional logit coefficients

Variables	Coef.	Robust S.E.
AvgTimeSinceADSLhat	0.787	0.053***
AvgTimeSinceADSLhat^2	-0.0782	0.00795***
WirelessCov	-0.24	0.0691***
PCOwnerYes	[REF]	
PCOwnerNo	-2.36	0.273***
PCOwnerNS	-3.8	0.787***
SocialClassABC	[REF]	
SocialClassD	0.686	0.384*
SocialClassEF	-0.107	0.331
SocialClassGJ	-0.208	0.552
SocialClassHI	-0.382	0.327
SocialClassZ	0.0919	0.297
EconWork	[REF]	
EconLk1stJob	3.85	1.97**
EconUnemp	-0.124	0.769
EconStudent	-0.756	0.731
EconHome	2.2	0.53***
EconRetired	2.35	0.623***
EconDisabled	0.409	0.646
EconOther	-0.286	0.768
AccHouse	[REF]	
AccFlat	-0.154	0.136
AccBedsit	-3.83	0.642***
AccOther	-2.07	0.914**
AccNS	0.308	0.799
Age0-14	-0.615	0.567
Age15-24	1.23	0.676*
Age25-44	[REF]	
Age45-64	0.203	0.382
Age65+	-2.28	0.663***

Variables	Coef.	Robust S.E.
IndAgric	0.331	0.431
IndBuilding	1.31	0.389***
IndManufac	1.32	0.329***
IndCommerce	[REF]	
IndTransComms	0.986	0.579*
IndPublic	-0.243	0.468
IndProfess	-0.198	0.334
IndOther	0.471	0.355
CompSingle	1.11	0.31***
CompCouple	0.732	0.319**
CompSingle&k	1.32	0.382***
CompCouple&k	[REF]	
CompOthFam	0.421	0.481
CompOtherNR	0.215	0.382
EduNone	-0.47	1.18
EduPrimary	-0.353	0.254
EduLwrSec	-1.35	0.349***
EduHighrSec	[REF]	
EduDegree	1.04	0.515**
EduPostgrad	0.692	0.641
EduNS	0.136	0.411
IrishSpeakers	0.0207	0.273
ForeignBorn	-0.0589	0.184
PersStillEducat	0.904	0.737
HomeWorkers	0.321	0.456
Ln(AvgIncome)	-0.219	0.188
Constant	-0.7	1.89

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