An Estimation of UK Telephone Access Demand Using Pseudo-Panel Data
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1 Introduction

In recent years, there has been rising concern about the impact of liberalisation on universal service in the telecommunications industry. The gradual removal of internal cross-subsidies as practised in the monopolistic telecom markets has brought about a rebalancing of telephone tariff structures. The opening of the market to competitive forces has forced the alignment of tariffs with costs. There is concern that the increase in connection and rental charges, as well as in local call charges, that has accompanied the fall in long distance and international call prices, may have a negative impact on the universal affordability of the telephone service. Reflecting this concern, national and European regulatory agencies have emphasized the importance of maintaining the high, pre-liberalisation standard of universal accessibility and affordability. The general feeling is that measures are needed to avoid the tendency for lucrative corporate user market benefits to be realized at the expense of some categories of residential customers.

In this article we address three questions. First, what is the impact of access price variations on residential telephone access in the UK? Second, which socio-demographic variables influence telephone access beyond the price dimension? And finally, are certain socio-demographic groups - low income, the elderly, single mothers - burdened disproportionately by the rebalancing of prices?

We estimate a telephone access demand model to obtain elasticity measures allowing us to assess the threat of drop-off caused by increased access charges. Earlier studies of telephone access demand commonly …nd that demand is quite inelastic with respect to price. However, small access elasticities for the population at large might mask much larger values for speci…c groups. Evidence from the US based on micro-data seems to support this argument. See for instance Cain and Macdonald (1991). Targeted support programs for these population groups should be considered to improve their access to the telephone. The identi…cation of characteristics which make a household more or less likely to have telephone access facilitates the formulation of targeted subsidy programs. We believe such subsidy programs are an economically e¢cient tool for maintaining universal service goals and improving telephone penetration among marginalised population groups.

The main objective of this paper is the estimation of a demand model for telephone access based on UK household data. This objective is motivated by a gap in the literature. Very little evidence in the UK concentrates on access and few studies are based on household data. One explanation for the relative lack of evidence on access demand in the UK compared with North America is the structure of the telecoms market in Europe. In Europe, the monopolistic provision of telecommunication services was accompanied by a uniform pricing policy which has remained even after liberalisation e¤orts. This excludes the use of pure cross-section studies for the purpose of assessing price elasticities (the “North American” model). In order to estimate the impact of price movements on household access despite this market organisation, we construct a data set with a repeated cross-section structure. The estimation method based on pseudo-panels makes it possible to consistently estimate elasticities from this data. Thus we can model the household decision on telephone access in a discrete choice framework where the telephone service decision is related to the cost of connection, household income and a host of other socio-demographic factors. Our results suggest UK price elasticities lying within the spectrum of results reported for North America. We also …nd evidence of substantially higher access elasticities for lower income groups thus con…rming the marked income sensitivity of access.

The remainder of the article is structured as follows: Section 2 gives a brief overview of the evidence on telephone access elasticities in North America and the UK. Section 3 describes our modelling approach and the data used. Section 4 outlines the pseudo-panel econometric technique. In section 5 we summarize and assess the empirical results. Section 6 concludes.

2 Review of the Evidence

2.1 North America

One of the main sources of information on telephone demand is Taylor’s (1980 and 1994) survey of the theoretical and empirical literature. Taylor notes that the erosion of the internal cross-subsidies in the telecoms industry meant that US research in the

1980's has seen an increase in the number of studies on the demand for residential access. The literature on access remains meagre, however, compared to that on call demand. One of the main reasons for this limited evidence stems from the fact that historically the US market has been characterized by local calls and access being bundled together[1]. Consequently much of the literature analyses this bundled service and not access as a separate service. The empirical debate in the US has centered around the question of whether or not elasticities are signi…cantly di¤erent from zero. Taylor (1994) reports of only eight studies which had been published on telephone access pre-1980. Five of these use aggregate time-series data[2]. The remaining three use cross-section data, but only Perl (1978) estimates a model based on household data[3]. Taylor (1994) summarizes the evidence on access by giving a range for the basic service charge elasticity of -0.06 to -0.17, with a mean of around -0.1. Considerably smaller …gures are quoted for the initial connection charge (-0.02 to -0.04). Income elasticities were centered around 0.5. Taylor suggests that residential access price elasticities have fallen somewhat during the 1980's due to higher penetration rates. Overall Taylor concludes that: "a very small price elasticity and a moderate, but yet decidedly inelastic income elasticity is precisely what one should expect for basic telephone service: access to the telephone system is not a plaything of the rich....but has become a basic necessity for virtually all income groups." (Taylor, 1994, p279).

The small, but nevertheless nonzero, access elasticities obtained pre-1980 have been con…rmed and sharpened in the 1980's. See for instance Perl (1983) , Taylor and Kirdel (1990), and Cain and Macdonald (1991). More recently, a number of applied studies using increasingly sophisticated quantal choice models have allowed for the fact that today residential users in the US face a multiple tari¤ choice for telephone access. Studies analyzing access elasticities in the context of multiple tari¤ options include Kirdel (1988) , Kirdel and Taylor (1993), Train, McFadden and Ben-Akiva (1987), Train, Ben-Akiva and Atherton (1989) and Train (1994).

From access demand studies for the US, the consensus emerges that the probability of having a telephone is sensitive to price, but the sensitivity is quantitatively small in aggregated terms. However, early on, Perl (1978) found that access elasticities are sensitive to the level of household income. This result has been con…rmed in subsequent studies. Cain and Macdonald (1991) focus on this particular aspect and …nd that some elasticities are up to twice as high for the poorest income households. Households most vulnerable to drop-o¤ due to rising local rates are young, low-income, poorly educated households living in rural areas.

[1] In the case of bundled local service, a unique …xed rental charge includes an unlimited number of local calls. Measured local service was gradually introduced throughout the US in the 1980s.

[2] The …ve time-series studies mentioned by Taylor are Rash (1971); Davis et al. (1973); Waverman (1974); Pousette (1976); and Southern New England Telephone Co. (1977). Waverman and Pousette use the only European, namely Swedish, data.

[3] The three studies are Alleman (1977) who uses data on a city level, Feldman (1976) who uses data on state level, and Perl (1978) who uses 1970 Census data.

2.2 United Kingdom

There is little formal work on access demand in the UK. British Telecom (BT) has conducted a number of studies on telephone demand, the results of which have been published in Cracknell (1982 and 1988), Cracknell and White (1989), and Cracknell and Knott (1995). The models yield estimates of the income and price elasticities for different services, mainly with the aim of improving commercial prediction and assessment of marketing strategies. This focus makes it more difficult to achieve a meaningful direct comparison with other studies in the field.

BT's statistics of residential system growth separately identify demand for new exchange lines, cessations and takeovers of existing lines and therefore allow a more detailed analysis of access behaviour (Cracknell, 1988). A working line was left for take-over in 84 percent of houses where the previous occupant had moved out. 92 percent of these takeover offers where taken up by the new occupant. Even among previously untelephoned households take-up was 85 percent. These rates are much higher than the 7 percent of non-movers who joined the network. The statistics show that, in the UK, household mobility provides a substantial impetus to the expansion of the telephone network, while the popularity of taking over service confirms evidence that installation charges can be a powerful deterrent. Analysis of cross-section take-up rates at different prices for different customer groups (e.g. new customers, moved customers, or take-up) gives an implied price elasticity of the order of -0.85 (Cracknell 1988)[4].

BT has also undertaken market research into the reasons for residential cessations (Cracknell and White, 1989). For a sample of 450 household in which there had been a change of telephone service in the previous year, 25 percent were customers who had not moved and had ceased their lines. In 7 percent of cases, service was subsequently reprovided to the same number. The majority of disconnections are due to conversion of premises, demolition or delay in re-occupation. A demographic analysis of the non-moving ceasers showed that they tend to be younger households, who are either in unskilled manual work or unemployed with recently born children, living in council accommodation. In a cross-section analysis based on BT's market panel, income proved the most powerful variable to explain residential system growth with a cross-section elasticity of 0.47. Other significant correlations were found between penetration rate and household size, rural versus inner city location, employment status, and number of rooms occupied (a measure of household wealth). Type of tenancy was not found to be a significant influence. A (non-significant) price elasticity of -0.063 with respect to the annual rental charge was established by a BT study quoted in Cracknell and White (1989).

[4] This result is so much higher than others reviewed so far because the price range considered is very different: the connection charge for a new customer is GBP105, while take-ever only costs GBP16 (Cracknell, 1988, presumably 1987 prices excl.VAT). Other access studies only consider the variation in the connection charge for new customers.

In an empirical study based on data from the telephone system in Hull (UK)[5], Trotter (1989 and 1996) produces separate demand estimates for access, local and trunk call prices. The focus of his access demand estimation is for access on a particular tari¤, rather than for access as a whole. This is due to the fact that the Hull system has had multi-tari¤ characteristics during a long period and there is thus no single access charge. Trotter uses aggregate time-series data covering the period 1974/75 to 1986/87. The price variables are complemented by aggregate measures of GDP and variables linked to alternative tari¤ choices (essentially rentals of alternative options available to residential users).

When analyzing the main residential tari¤, Trotter (1996) …nds that neither levels nor changes in rentals seem to play a meaningful role in explaining the number of customers on the main residential tari¤. Nor does the connection charge. This may be because it was relatively stable over the period or because it is lower than the BT equivalent. The lagged number of customers on the tari¤ is highly explanatory. However, this is to be expected considering the strong time trend present in the telephone penetration variable. Because of the small number of observations, the results are not very stable. Nevertheless, Trotter reports a short-run access elasticity of 0.6 with respect to income and of -0.1 with respect to the rental charge of the main residential tari¤.

Summing up, some general conclusions appear to hold for North America and the UK. Price elasticities for telephone services are small but greater than zero and increase with distance, with access being the smallest in absolute terms and international calls the largest. The assessment of access elasticities and the comparison of US and UK evidence is, however, less than straightforward. Many of the US studies refer to basic local service, i.e. bundled local access and local calls, whereas UK studies are rare and mostly based on time series. Reported rental elasticities ("basic local service") have an average size of -0.1 in the US, their UK counterpart (line rental only) ranges between -0.06 and -0.1. Income elasticities of access center around 0.5 for the US, and vary between 0.5 and 0.6 in the UK. For connection charges, US elasticity estimates are in the range of -0.02 to -0.04, for the UK only Cracknell (1988) gives an estimation of a connection charge elasticity which is -0.85. Unfortunately, the method used in calculating this last number di¤ers too much from the other estimates to allow any direct comparison. Overall, we believe that, despite the similarities in the size of the estimates, a comparison across the Atlantic needs to be done with caution. The di¤erences in the respective telecoms environments have to be taken into account, as have the di¤erent de…nitions for various services. Cracknell and Knott (1995) stress the sensitivity of elasticity calculations with respect to the underlying data. However, the similarity in the range of the results across the Atlantic is notable. The

[5] Kingston Communications (Hull) plc is a telecommunications company wholly owned by Kingston-upon-Hull City Council. It holds a licence under the 1984 Telecommunications Act to provide all telecommunications network services in the Hull licensed area. This area has a population of around 350 000 people serviced by some 150 000 exchange connections.

socio-demographic variables playing a role in determining access include income, age, education and employment status on both sides of the Atlantic.

3 Model and Data

3.1 Model

One of the most important features of telecommunications demand is the interdependence between telephone access and telephone usage. Access refers to the consumer's ability to make and receive[6] telephone calls, and logically precedes usage, which refers to calls actually made. Making a telephone call is dependent on a prior decision to subscribe to the telephone network. However, telephone access does not automatically imply usage. Due to option demand, a consumer may desire to have access even though no calls are made. Option demand refers to the bene…ts that come from being able to make and receive calls which are not in fact made or received. The most quoted example is the ability to call medical or rescue services in an emergency. It is easy to imagine that consumers are willing to pay for this bene…t separately.

The theoretical basis for most access demand studies is the consumer surplus framework, in which the demand for access to a telephone network is related to the net bene…t from usage of the network, as measured by consumer surplus. Households will decide to have a telephone if the value of consumer surplus from using a telephone exceeds the price of access. Wenders (1987) argues that the consumer surplus obtained from the surface area below the call demand curve should be augmented by the value to the consumer of receiving incoming calls, plus the "option value" of being able to make or receive further calls if she wishes.

The consumer surplus framework easily lends itself to the formulation of a quantal-choice model by viewing consumer surplus as a random variable whose mean is related to prices, income and other relevant socio-demographic variables. A normal distribution leads to the probit model, while a logistic distribution leads to the logit model. Probit/logit models can alternatively be derived in a random utility framework, as in, for example, the models of Train, McFadden and Ben-Akiva (1987) and Train (1994)
.

Taylor draws on previous work by several authors to derive a cohesive theoretical structure to model telephone demand. The key elements of his discussion are outlined here[7].

We assume the individual maximizes a utility function

$$U = u(\pm q; x; \pm N) \tag{1}$$

[6] Note that the distinction between making and receiving calls is increasingly important in the face of regulatory tendencies emerging at present. Disconnection from the telephone service is replaced by a policy of barring outgoing calls due to concerns about universal service.

[7] See Taylor 1994 , pp23-35, for full details.

where

δ = 1 if the consumer is connected to the telephone system, 0 if not;
q = the number of telephone calls;
x = consumption of composite good;
N = number of subscribers to the system;

subject to a budget constraint

$$\delta(r + \pi q) + px = \mu \tag{2}$$

where

π = price of a call;
p = price of a composite good x;
r = price of access to the system[8];
μ = income of the consumer.

The demand functions are derived by a two-step procedure: maximisation of (1) subject to (2) assuming $\delta = 1$, and comparison of the resulting consumer's surplus with that if $\delta = 0$. The first step leads to the following expression for the consumer's surplus (S) from making q^0 calls, where $g(.)$ is the inverse demand function for calls:

$$S = \int_0^{q^0} g(q; p; N; \mu - r)\,dq - \pi q^0 \tag{3}$$

In step two these benefits are compared with the cost of access to the system, and the consumer will subscribe if the former exceeds the latter:

$$\delta = \begin{cases} 1 & \text{if } S \geq r \\ 0 & \text{if } S < r \end{cases}$$

The analysis is then extended to an entire population. The demand for use is now identified with the total number of calls, Q, whereas the demand for access is equated with the proportion of the total population that subscribes to the telephone system. Q is given by

$$Q = Q(\pi; p; r; N; Y) \tag{4}$$

Defining δ_n as either 1 or 0 according to whether individual n is a subscriber,

$$N = \sum_{n=1}^{N} \delta_n \tag{5}$$

[8] The price of access to the system is the non-traffic sensitive part of the cost of being connected to the telephone network. It is mostly twofold. First, there is a unique connection (or installation) charge to be paid the moment access to the network is desired, then a line rental charge has to be paid with every bill.

The quantity that we wish to explain is the proportion of the population which does subscribe, N/M, where M is the total population.

Define S_n analogously to S above:

$$S_n = \int_0^{q'_n} g_n(q; p; N; \mu_n - r)dq - \pi q'_n \tag{6}$$

Each individual will again compare his or her value of S_n with r. δ_n will vary across individual consumers because of differences in either tastes or income. Taylor assumes that all consumers have the same preferences, so that it is income that varies. More precisely, given a distribution of income, N will be determined by the probability that S_n is greater than r:

$$\begin{aligned} P(S_n > r) &= 1 - f(r) \\ &= 1 - \int_0^r f(S_n)dS_n \end{aligned} \tag{7}$$

where $f(S_n)$ and $F(S_n)$ are the density and distribution functions of S_n. The distribution of S_n will be related to that of income via the "change of variable" from μ_n to S_n defined in (6). μ is a random variable. In fact Taylor shows that (7) can be rewritten as

$$\begin{aligned} \frac{N}{M} &= p(S_n > r) = P[\mu_n > \mu^*(r)] \\ &= 1 - \int_0^{\mu^*(r)} h(\mu_n)d\mu_n \end{aligned} \tag{8}$$

where $h(\mu_n)$ is the density function of μ and $\mu^*(r)$ is the income of the marginal subscriber.

Equation (8) gives

$$\frac{N}{M} = \int_{\mu^*(r)}^{\infty} h(\mu_n)d\mu_n \tag{9}$$

More generally (5) can be rewritten as

$$\frac{N}{M} = \Psi(\pi; p; r; N; Y) \tag{10}$$

where $\Psi(\cdot)$ is a composite function embodying S_n, the change in variable from f to h, and the integral in (9). Taylor concludes that equations (4) and (10) "comprise, in general form, a bare-bones model of telephone demand for a population of residential consumers" (Taylor 1994, p31).

The presence of N as an argument in both these equations brings out the second feature mentioned above, the role of externalities. These are of two types. One is the call externality, by which one person making a call affects (normally positively) the utility of the person being called. In general this is assumed to be internalised between the two beneficiaries. The other externality concerns access, and derives from the extra utility accruing to one subscriber if the number of other subscribers in the system increases. Its effect will be to reinforce the access-usage interdependence. The practical consequence is that we would expect demand to be more than unit elastic with respect to the number of customers on the system. Taylor (1980, p16) argues "it [the access externality] gives the telephone the dimension of a public good, since the benefit that a new subscriber confers on existing subscribers is shared in common." This argument has been used to support the case for subsidizing access, as the benefit as perceived by the individual subscriber will tend to understate the total benefit to society.

3.2 Data

The data set we use is based on 12 years of the UK Family Expenditure Survey (FES) spanning the period from 1985 to 1996. The FES is a continuous household survey that generates random samples of the population every year[9]. 10,000 UK households are selected every year. Of these approximately 7,000 complete the survey procedure and are included in the data set. Thus, our original sample comprises some 92,000 UK households. The sample period chosen avoids complications with respect to structural changes in the UK telephone industry, as 1984 is the year British Telecom was privatized. Moreover, price data becomes very difficult to trace for the pre-1984 period.

Beside very detailed information on expenditure on consumption and investment goods, the FES provides data on household characteristics. The socio-demographic information we use, such as education or sex, refers to the head of household. Other variables, such as income, refer to the household as a unit. In contrast to the US census survey, the FES does not comprise any information about the ethnic origin or the native language of the household, two variables which have been used in US studies on telephone demand to account for the size of the "calling circle" of a household. The FES survey includes a question about telephone access with the wording: "Is there a telephone installed in your accommodation?". We coded the answer in a binary 0-1 mode. Telephone access in this model is therefore defined in terms of access within the home.

[9] We are grateful to the ESRC Data Archive in Essex for providing us with the FES data.

4 Method of Estimation

The key di¤erence between the US and the UK in terms of modelling telephone demand stems from the di¤erent organizational structure of the industry in the two countries. US studies are mainly based on countrywide census data. See, for example, Perl (1983), Cain and Macdonald (1991) , or Taylor and Kirdel (1990). Due to the presence of a multitude of telephone operators created after the divestiture of AT&T in 1984[10], di¤erent prices for telephone access and call services are charged in di¤erent regions and cities of the US at any given moment. Therefore, a single countrywide US data set comprises not only variation in socio-demographic variables, but also variation in price variables. By contrast, most European countries, including the UK, have a long history of monopoly provision accompanied by a policy of uniform pricing at the national level. Even after the liberalisation of the UK telecommunications market in 1984, British Telecom retains almost the entire market of residential access[11]. For this reason, there is still predominantly a unique price for telephone connection and quarterly line rental. Because of this market structure, price variation necessary to estimate the access elasticities of telephone demand is only available across time. Thus, a unique cross-section data set such as generated by one set of census data will not provide the necessary price dimension for our analysis. To remedy this problem, we base our study on a combined time series/cross-section data set. In this way, a simultaneous analysis of the in‡uence of socio-demographic and price variables is possible.

We compile 12 years of the UK FES data to estimate the model outlined in the previous section and to …nd empirical values for the price and income elasticities of telephone access. In order to consistently estimate a model based on data generated by repeated and independent cross-sections, econometric techniques adapted to this data structure have to be employed. In his seminal article, Deaton (1985) shows that a …xed e¤ect model can be identi…ed and consistently estimated from repeated cross-section (RCS) data. He suggests grouping individuals sharing some common observed characteristics, like age or sex, into cohorts. The averages within these cohorts are then treated as observations in a pseudo-panel (or synthetic panel, Verbeek, 1992) to which standard techniques for panel data estimation can be applied. Such synthetic panels might even have certain advantages over pure panel data, notably the preservation of randomness due to the absence of attrition.

[10] Known as Regional Bell Operating Companies (RBOCs).

[11] At the same time, the more lucrative corporate and long-distance call market has become increasingly competitive. Also, this assessment of BT's share of the residential access market is valid for the sample period used, i.e. 1985-1996. At the moment of the publication of this paper, cable companies are busy eroding BT's share in the residential market, a phenomenon which would have to be taken into account in future analysis.

4.1 Pseudo Panel Estimation

Suppose that y_{it} is a $0-1$ variable indicating whether a household has access to a telephone or not, and that this indicator variable is a linear function of explanatory variables. We acknowledge this being an unusual assumption as in reality it is not possible for a $0-1$ indicator to be a linear function of variables, since the linear function can take any value whereas the indicator is binary. However, the estimation procedure which we have adopted involves subsequent aggregation of the individual data. We need y_{it} to be linear in the explanatory vriables in order for the aggregation to give a relation between the share of 1's and the average of the explanatory variables[12].

Consider now the basic linear individual effect model

$$y_{it} = \alpha_i + X_{it}\beta + u_{it} \qquad i = 1, \ldots N; \qquad t = 1, \ldots T \tag{11}$$

where X_{it} is a $(K \times 1)$ vector of explanatory variables which we assume exogenous to the model, index t and i refer to time and individuals respectively. Note that as we are not dealing with a real panel, N can vary from period to period while T is fixed. The disturbances of the model (11) are assumed to be i.i.d., with zero mean and variance σ_u^2. We also assume that the individual effects α_i are i.i.d. with finite mean and variance σ_α^2. If the α_i's are assumed to be the same across all units, OLS provides consistent estimators of α and β: Complications arise from the fact that the individual effects are assumed to be uncorrelated with the disturbances but potentially correlated with the regressors. If the individual effects are uncorrelated with the explanatory variables X_{it}, the model can easily be estimated from RCS by pooling all observations and performing OLS treating $\alpha_i + u_{it}$ as a composite error term. However, in many applications the individual effects α_i are likely to be correlated with X_{it} , so that estimation procedures treating the α_i as random drawings from some distribution, such as simple pooling or the random effects model, lead to inconsistent estimators, unless the correlation is explicitly taken into account. When panel data are available, this problem can be solved by treating the α_i as unknown, but estimable, parameters. Obviously this strategy no longer applies if no repeated observations on the same individuals are available. When the model is to be identified by means of RCS data, an additional incidental parameter problem arises: $NT + K$ parameters have to be estimated from NT observations. Deaton (1985) suggests the use of cohorts to obtain consistent estimators for β in (11) if repeated cross-sections are available and the individual effects are correlated with the regressors.

Define C cohorts, which are groups of individuals sharing some common characteristics like sex or date of birth. These groups are defined in such a manner that each individual is a member of exactly one cohort, and remains a member of this cohort for all periods. For example, a particular cohort may consist of all male individuals

[12] We are grateful to an anonymous referee for pointing out this problem of an aggregation bias created by the estimation method.

born in 1945-1949. Assuming, for simplicity, that there is a unique regressor ($K = 1$), if we aggregate all observations to cohort level, the resulting model can be written as

$$\bar{y}_{ct} = \bar{\alpha}_{ct} + \beta \bar{x}_{ct} + \bar{u}_{ct} \qquad c = 1, \ldots, C \tag{12}$$

If we define n_{ct} as being the size of group c at time t; $\bar{x}_{ct} = n_{ct}^{-1} \sum_{i \in c}^{t} x_{is}$ is the average value of all observed x_{it}'s in cohort c at time t, and analogously for the other variables in the model. The resulting data set is a pseudo panel with repeated observations over T periods and C cohorts. The main problem with estimating (12) is that $\bar{\alpha}_{ct}$ depends on t; is unobserved and is still likely to be correlated with $\bar{x}_{ct}$. Therefore, treating $\bar{\alpha}_{ct}$ as random error is likely to lead to inconsistent estimators, while treating them as fixed unknown parameters results in an identification problem unless the variations over t can be ignored ($\bar{\alpha}_{ct} = \bar{\alpha}_c$). If the cohort averages are based on a large number of individual observations, this assumption seems reasonable (see for instance Verbeek and Nijman, 1992, on the asymptotic properties of the cohort estimators). Under these assumptions, a natural estimator for β is the covariance, or within, estimator $\hat{\beta}_w$ used on the weighted cohort means[13].

Let $\bar{x}_c = \left(\sum_{t=1} n_{ct}\right)^{-1} \sum_{t=1} \bar{x}_{ct} n_{ct}$ be the time average of the observed cohort means for cohort c, and define $\bar{y}_c$ likewise. The weighted within estimator on the pseudo panel observations is, for the case of a single regressor:

$$\hat{\beta}_w = \left(\sum_{c=1} \sum_{t=1} n_{ct} \left(\bar{x}_{ct} - \bar{x}_c\right)^2 \right)^{-1} \left(\sum_{c=1} \sum_{t=1} n_{ct} \left(\bar{x}_{ct} - \bar{x}_c\right)\left(\bar{y}_{ct} - \bar{y}_c\right) \right) \tag{13}$$

$\hat{\beta}_w$ is biased in small samples but consistent as the size of each group n_{ct} tends to infinity, provided standard assumptions on the second moments of the regressors hold (Moffitt, 1993). When the size of each cohort is large enough, the sample mean of the fixed effects provides a consistent estimator of the time-invariant population mean and the estimator given in (13) is consistent. Consequently, when n_c is reasonably large, most applied studies ignore the errors-in-variables problem caused by the possible time variation in $\bar{\alpha}_{ct}$ and use standard estimators like the within estimator. See for example Browning et al.(1985). Our study falls into this category as the average cohort size for our sample is sufficiently large.

Note also that there is a trade-off between the number of observations in the pseudo panel and the accuracy of these observations. The larger n_c, the smaller C. In the case of the standard within estimator $\hat{\beta}_w$, this means a trade-off between the bias and variance of the estimator.

[13] The weights are introduced to account for heteroscedasticity across cohorts.

5 Empirical Results

We model the demand for telephone access as a function of two groups of variables: price variables and socio-demographic variables. These variables determine the calling pattern of the household and therefore its access demand. The model we specify seeks to explain telephone access as a function of real connection charges and real line rental, which we expect to have a negative impact on telephone access, as well as real net household income, which has an expected positive in‡uence. We also introduce household income in squared form to account for possible non-linearities. The total number of household members is equally expected to increase the demand for telephone usage and therefore for telephone access. In addition, we introduce measures for retired and female heads of household. Socio-economic studies about the "untelephoned" (see for instance OFTEL, 1994) …nd that these groups are more likely to be connected to the telephone, possibly re‡ecting higher option demand. We include the presence of children under …ve partly to adjust the household size variable for structural di¤erences in household composition, and partly to test for another possible option demand e¤ect.

Other household characteristics included are variables denoting a single-person household, the presence of an unemployed/unoccupied head of household, the age at which the head of household left full-time education, moreover a variable indicating rented accommodation, a "recent mover" variable, and …nally a variable which denotes an area with low population density. Single household status has been found to have a negative impact on telephone access in studies in the United States. The presence of an unemployed or unoccupied head of household is included to test for an in‡uence beyond the income e¤ect. The age at which the head of household left full-time education should in‡uence the demand for telephone access positively. As far as variables related to the household accommodation are concerned, we expect households living in rented accommodation to have a lower access demand because of the type of housing included in this category. It has also been argued that the calling circle of households living in rented accommodation is smaller than for households owning their accommodation (Cain and Macdonald, 1991). The recent mover variable has been included to account for households not yet having had the time to get connected to the telephone. The …nal explanatory variable denotes households living in administrative areas with under 3.2 persons per acre (7.9 persons per hectar) and is included to account for spacial patterns in the telephone penetration rate.

For the estimation of our model, we divide the individual households into groups based on the date of birth of the head of household. We include households whose head was born between 1910 and 1963, that is, heads of household who were between 22 and 74 years old in 1985, the initial year of our sample. To form the pseudo-panel cohorts, we regroup the date of birth groups into pairs. Thus, the …rst cohort comprises households whose head was born in 1910 or 1911, the second households whose head was born in 1912 or 1913, and so on. This guarantees a su¢ciently large number of

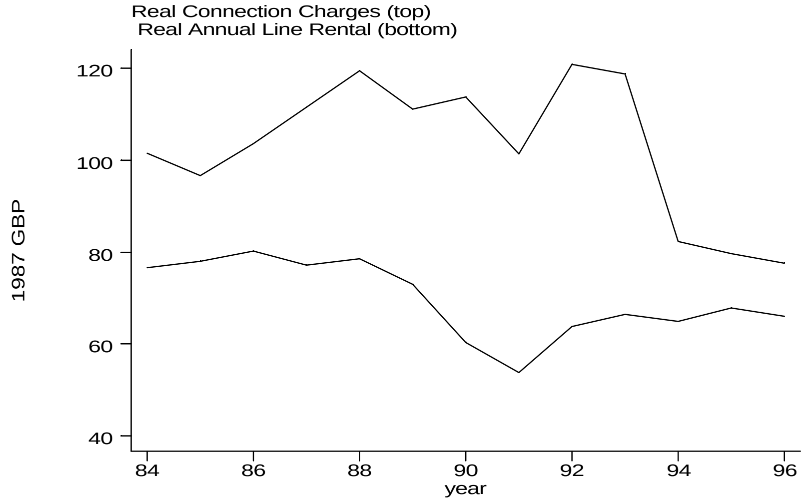

Figure 1: BT connection charges and annual line rental

observations in each cohort. In this manner, we create a pseudo-panel comprising 27 cohorts over 12 years, i.e. a sample with 324 observations overall. Our mean cohort size is 226. The total number of households forming the basis of the overall cohort sample is approximately 73,300. Note that while the original model as defined in theoretical terms in (11) is a binary model in the dependent variable and in a number of the explanatory variables, once the cohorts are formed, the observations take on the value of cohort means and represent proportions. The binary variable indicating a female head of household, for example, is now the proportion of households headed by a woman for a given cohort at a given time. We perform a logarithmic transformation on the dependent variable to make sure that the proportion estimated is bound by the [0,1] interval. The price variables included in the model are the connection charge BT charges new customers as well as BT's annual line rental charge[14]. The connection charge varied between £77.5 and £121 in real terms (1987 prices) between 1985 and 1996, the real annual line rental between £54 and £80. The evolution of the two access prices over time can be seen in Figure 1. The annual mean telephone penetration rate calculated from our sample over the same time period is pictured in Figure 2.

We estimate the model by means of the weighted within estimator given in (13). The results of the estimation are reported in the second column of Table 1. Given the original form of the data, namely random samples taken from a large population, we have undertaken a Hausman test to test the specification of the model as fixed rather than random effect model. The null hypothesis of orthogonality of the α_i and X_{it} is rejected and the fixed effect specification is therefore accepted as appropriate.

[14] We are grateful to Eurodata, London, for providing us with the telephone price data used in this article.

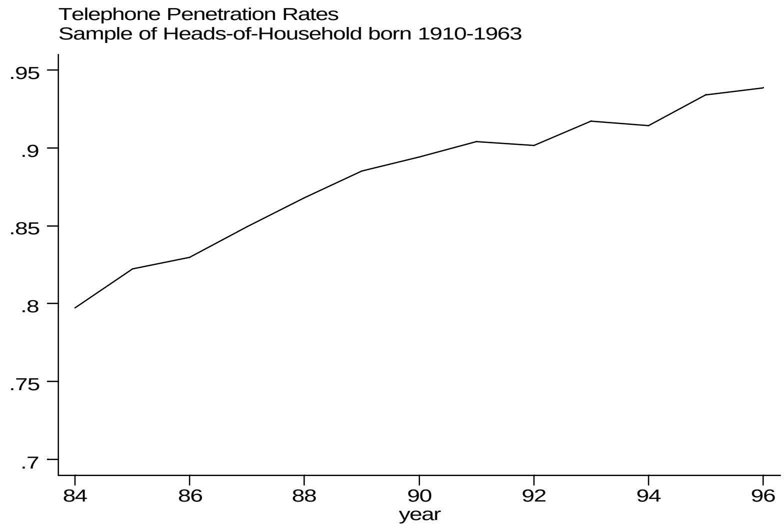

Figure 2: Telephone penetration rates

Table 1: Estimation Results				
Indep. Variable¤	Coe¢cients (t-stat. in parentheses)			
	Overall Sample		Low-Educ.Sample	
connection charge	-0.0056	(-5.01)	-0.0062	(-4.64)
rental charge	-0.0043	(-1.67)	-0.0067	(-2.3)
household income	0.006	(4.32)	0.0065	(3.68)
household income^2	-9.06e-07	(-2.39)	-1.03e-06	(-1.99)
retired HoH	1.27	(5.03)	1.12	(4.17)
female HoH	3.03	(5.00)	2.49	(4.63)
rented accomod.	-4.46	(-8.32)	-3.24	(-7.35)
person total in HH	-0.013	(-0.125)	-0.02	(-0.17)
%age of child. <5	-0.574	(-0.585)	-2.24	(-2.1)
unem./unocc.HoH	0.87	(1.75)	0.66	(1.41)
single person HH	-0.774	(-1.24)	-0.21	(-0.35)
left f-t education	0.283	(3.5)	0.33	(2.72)
recent mover	-3.69	(-3.39)	-1.79	(-1.66)
area density	0.89	(2.05)	0.34	(0.834)
const.	-2.92	(-2.16)	-3.2	(-1.8)
F-Test	1.31		1.21	
Adjusted R^2	0.75		0.685	
"$_y$	0.14		0.176	
"$_c$	-0.065		-0.1	
"$_r$	-0.033		-0.07	
mean cohort size	226		129	

¤HoH = head of household, HH= household

The coefficients of household income and the connection charge have the expected sign and are statistically highly significant. The coefficient of the annual rental charge is negative, and while the statistical significance level for this price variable is lower, it is still within the 10 percent confidence interval. The small but negative coefficients for the two price variables confirm the deterrent represented by telephone access charges. Calculated at the sample mean, the coefficient for the connection charge gives rise to an access elasticity of -0.065 which lies above the range of connection charge elasticities reviewed by Taylor (1980) (-0.02 to -0.04), but within the results quoted by Cain and McDonald (1991). The coefficient for annual line rental in turn suggests an elasticity measure of -0.033 which is lower than the results reviewed earlier in this article. Our results suggest that it is primarily the connection charge which represents a barrier to telephone ownership. This argument is supported by the findings of the 1994 OFTEL report on the untelephoned. For household income, the coefficient leads to an income elasticity of 0.14, which is lower than the average results reported earlier. However, our result is in line with the findings of Waverman (1974) and Perl (1976). In both cases the estimate of the income elasticity is 0.15 (Taylor, 1994, p279). Like Perl's, our elasticity is estimated with a model in which other factors related to income, such as education or type of housing, are taken into account. Thus a smaller income elasticity is probably to be expected. The significant coefficient of the squared income variable suggests that there might be a non-linear effect in this variable.

A majority of the socio-demographic variables included as explanatory variables for access demand have significant coefficients. Households headed by someone with higher education level are more likely to have a telephone in their living quarters, as are households headed by a retired or female person. This seems to suggest a higher option demand for this population group. However, other variables included to account for household structure, such as household size or the percentage of children under five, do not seem to have a statistically significant impact on telephone access demand. Neither does the single person household status. A household headed by a unemployed person or one without occupation has a positive coefficient indicating a higher probability of telephone access for this population group. This result might partly be due to the definition of this category. In particular the latter group included in the category unemployed/unoccupied might contain households with a high propensity for telephone access. There may also be an effect due to a social security system which accords allowances for utility bills. Living in rented accommodation influences telephone access negatively, which is to be expected as most of the dwellings included in the category "rented accommodation" in the UK are council housing or belong to housing associations. Households living in rented accommodation are therefore likely to have a lower than average income. Having recently moved to the current address has a statistically strong effect and diminishes the probability of the household being connected to the telephone. Living in an area with very low population density also leads to a higher demand for telephone access as could be expected given the higher cost of alternative means of communication, such as personal visits, for households living in remote areas.

Overall, it is income and variables related to income such as education or type of housing, together with variables indicating female or retired heads of household which have the strongest impact on telephone access among the socio-economic variables. This result corroborates the findings of the main US studies surveyed in Section 2. A "recent mover effect" can also be clearly identified.

5.1 Differentiation of the results according to income

Progress toward universal service is generally measured by the percentage of households with telephone service. Despite a high aggregate level of the household penetration rate, an important differential between population groups exists. Cain and Macdonald (1991) find that price elasticities differ substantially between low and high income groups. The impact of higher fixed charges will therefore be born disproportionately by the low-income part of the population. The (arc) price elasticities for connection charges calculated by Cain and Macdonald (1991) range from -0.04 to -0.2 with greater elasticities in households with lower initial connection probability, mainly low-income households from minority groups. In order to test the sensitivity of the access elasticity with respect to income in our sample, we divide our data into two subgroups. We create cohorts which are not only based on date of birth, but also on the age at which the head of household left full-time education. This latter variable serves as a time-invariant proxy for household income and allows us to partition our sample according to a variable strongly correlated with income. We define people who left full-time education at or below the legal age as belonging to a "lower education" group[15]. We then apply the pseudo-panel technique to the lower education sample to test for differences in the results for this subgroup. The estimation results for the "lower-education" sample are reported in column 3 of Table 1.

The heads of roughly 42,000 households born between 1910 and 1963 left school at or below the legal school leaving age. We regroup them into two-year cohorts following the same procedure outlined above. The mean cohort size is 129. Column 3 shows us that the income and price variables have significant coefficients which give rise to elasticities of 0.176 for income and -0.1 and -0.07 for connection charge and line rental respectively (all calculated at sample mean values). The price elasticities in the lower-education population are therefore 50 percent and 100 percent higher than the elasticities calculated for the overall population. We conclude that the lower education/lower income group is indeed more sensitive to changes in telephone access

[15] We also need to account for the fact that the legal age for school leavers has changed over time. Our sample includes individuals born between 1910 and 1963. While these were at school, the legal age first changed from 14 to 15 (1946) and then from 15 to 16 (1973). A person born for instance in 1930 is thus "higher-educated" if they left school at 16, while another, born for instance in 1960, is "lower-educated" if they left school at the same age of 16.

charges than the overall population. The income elasticity is also higher, although its rise by 25 percent is not quite as marked as that of the price variable elasticities. There is little change of behaviour among the socio-demographic variables. Retirement, gender and education have a statistically significant positive influence on the telephone penetration rate, while living in rented accommodation has a strong negative effect. Household size is still statistically non-significant, but our results suggest that the number of children under five has a negative influence on telephone access among the lower-education population, whereas it did not have a significant impact in the overall sample. This result might be interpreted in terms of a liquidity effect. The presence of infants in low-income households might present a strain on household income which can be seen in lower telephone access rates, a phenomenon which is not apparent in the population at large. Moving into the present dwelling within the last four months still has a negative sign but its significance level has dropped. Living in an area of under 3.2 persons per acre is no longer statistically significant for households in the lower-education sample.

5.2 Assessment of Results

The small but mostly significant negative price elasticities for connection and rental charges suggest that a substantial increase in these prices will have a noticeable negative effect on telephone penetration and therefore on the objective of achieving universal access across all groups of the population. Small elasticities can lead to large numbers when applied to a large population base[16]. The numbers give even more cause to concern if they are higher for disadvantaged, low-income groups as our results suggest. However, the elasticities calculated in this study should not be used in an unconditional manner to quantify drop-off. First, adjustment to increasing residential access charges will take place over time and not instantaneously. Second, telephone penetration is driven by a host of factors other than price which might evolve so as to counteract the effect of rising price levels.

Telephone penetration rates in the UK have risen steadily since the 1984 liberalisation despite changes in connection and line rental charges. One possible explanation is the change in the household structure during the same period. When focusing on the household characteristics which we identified as most influential on telephone access demand, we see that average weekly household income has increased from £183 to £213 (1987 prices) between 1985 and 1996, even though the growth of this variable has slowed in the first half of the 1990s. Also according to the FES data, the proportion of households headed by a retired or female person has increased over the same

[16] According to the 1991 population census there were 21 441 000 households in the UK at this moment. The telephone penetration rate calculated from the FES survey for that year was 90.4%, i.e. 19 383 000 households had in house access to the telephone. According to our elasticity calculation and assuming ceteris paribus, a 25% increase in the connection charge would lead to a 1.625% decrease in the quantity of people connected, which would signify 315 000 households less among those with telephone connection.

time period. The former group's share among total households has risen from 22 to 26 percent, the latter's from 23 to 26 percent[17]. The average education level measured by the age when full-time education ceased has risen from 15.5 to 16.1 years, in line with the increase in the compulsory schooling age. At the same time the frequency of rented accommodation decreased from 30.4 to 23.6 percent due to the government sale of council housing to their respective occupiers. To the extent that households with higher incomes, or headed by a retired person or a woman, as well as households living in owned accommodation have a higher demand for telephone access, we will expect rising telephone penetration as the household structure changes over time.

Is the evolution of factors influencing telephone penetration in the overall population mirrored in those parts of the population most likely not to have a telephone? It is the lowest income groups which are most threatened by further marginalisation due to increasing fixed charges. We select those households in the lowest ten percent income percentile for each year in the sample to search for potential differences in the behaviour of the socio-demographic variables for this population group. The most noteworthy difference between the overall sample and the lowest ten percent income group is the difference in their respective age structures. The average age among the lowest income populations is 60.7 years. This is ten years above the average age of all heads of household included in the FES survey between 1985 and 1996. Over the same period, the percentage of households headed by retired persons has risen from 41.6 to 57 percent, the proportion of those headed by women varied between 59 and 65 percent. For the greatest part the tendencies observed in the overall population are however mirrored by the households in the lowest ten percent income bracket. Average weekly household income has risen from £48 to £52.2 for this income group. The average education level has also increased from 14.4 to 14.9 years. The percentage of households living in rented accommodation has decreased from 48.4 percent in 1988 to 35.7 percent in 1995.

In view of the evolution of the variables identified in our model as influencing telephone access demand, we can find no evidence for the UK that there is an increase in the probability of marginalisation for the poorest population group as far as telephone access is concerned. This conclusion is confirmed by Figure 3. It shows the evolution of telephone penetration rates between 1985 and 1996 for the overall FES population sample and for the lowest 10 percent income households in this sample. The figure suggests a narrowing of the gap between the two groups. This narrowing appears to be mainly due to the increase in income and in the share of households headed by elderly and women in this population group.

[17] There is an obvious overlap between the variables though.

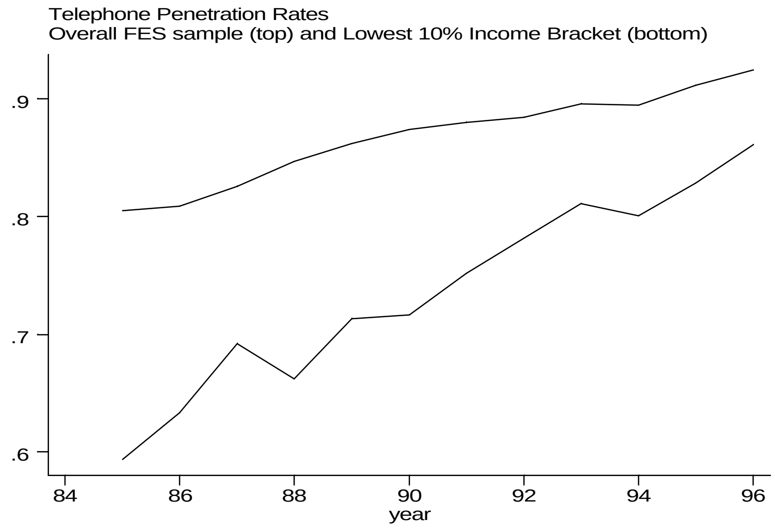

Figure 3: Telephone penetration rates differentiated according to income

6 Concluding Remarks

The liberalisation of the telecommunications sector and the rebalancing of the tariff structure associated with it has raised questions about the impact the rise in access charges will have on residential customers. The issue is of particular interest in view of universal service objectives proclaimed at national and European level. Through the creation of a repeated cross section data set based on the annual UK Family Expenditure Survey we were able to estimate the impact of tariff variations on residential telephone access demand.

Our work shares one drawback with other studies in this area. Our elasticity measures do not allow us to separate the impact on telephone penetration rates into "drop-off" resulting from higher connection and rental charges, and failure to "drop-in" by those still untelephoned. In view of this, our work is, however, useful in establishing two facts. First, the cost of access expressed by connection and rental charges has a negative effect, albeit small, on the probability of a household having a telephone. Second, we have identified a number of socio-demographic and economic household characteristics associated with telephone access.

By creating a subsample of low-education households to approximate low-income households, we also find a strong sensitivity of access elasticities with respect to income. Our study confirms the validity of US experience for the UK. For the overall sample, our price elasticity of -0.06 with respect to connection charges lies above the average of price elasticities summarized by Taylor (1994) but is in line with estimates found by Cain and Macdonald (1991). For the lower education sample, the corresponding price elasticity is -0.1. As far as the impact of the rental charge is concerned, the results show a negative impact on telephone access, the statistical significance of the results is however lower for this price variable, suggesting that the one-off connection charge is the main price barrier to telephone ownership. For the overall sample, we found a price elasticity with respect to the rental charge of -0.033. The measure is statistically more stable for the low-education sample were it leads to an elasticity of -0.07. The income elasticity of access is 0.14 for our overall sample. This is lower than the average estimate of 0.5 reported in studies surveyed by Taylor (1994), but in line with estimates reported by Waverman (1973) and Perl (1976). The fact that our estimate is lower is very likely a consequence of the inclusion of income related variables such as education or type of housing in our estimation model. Taylor (1994) argues that elasticities decrease as the penetration rate increases. If this argument holds for the UK, our results, based on the period 1985-1996, and very similar to results found up to 20 years ago for the US, would suggest that overall the absolute level of telephone access elasticities is higher in the UK than in the US.

Among the socio-demographic and economic household characteristics strongly influencing telephone access demand are household income and variables linked to income such as education and type of dwelling. The presence of a retired or female head of household also influences telephone access positively and suggests a stronger option demand for these population groups. We also found a clear "recent-mover" effect.

We can see from Figure 1 that after initial increases, BT's connection charge has fallen in real terms over the last few years, mainly because of the regulator's concern about disconnections. The negative price elasticities found in this study confirm that such regulatory efforts may help maintain and improve access levels. Nonetheless we believe that containing the access price at a below-cost level for the whole population is not necessary to improve telephone penetration among the low-income population. An economically more efficient way is offered by targeted subsidy programs, which target lower access charges at those truly threatened by exclusion. We believe that so far the potential of such pricing options has not been exploited in a satisfactory manner in the UK[18]. Targeted subsidy programs can take one of two forms: either they are based on some means-tested criteria (in some US states for instance telephone connection is facilitated for recipients of food stamps), or they take the form of optional (or self-selection) tariffs. This latter category of targeted subsidy programs has very desirable efficiency features. US results suggest that access demand is primarily a function of minimum rather than average access charges (Cain and Macdonald, 1991, and Train, 1994). This suggests that the provision of social tariffs can be expected to maintain relatively high levels of access demand even in the face of overall access charge rises. Tariffs with relatively low access but high usage

[18] The introduction of the "Low-User Scheme" in 1984 by BT has not been very successful. This tariff designed for the low-income customers has been critizised for offering too little in terms of fixed cost relief. If offered no reduction of connection charges and had therefore only limited appeal to those not yet connected.

charges for instance should appeal to low user groups such as certain elderly or lone parents which have a relatively small calling circle but a high option demand.

Finally, we note the following. In his 1994 survey of telephone demand, Taylor observes that while liberalization and technical progress have improved the quality of data on telephone demand, competition and privatisation has led to increased difficulties for researchers in obtaining access to data now considered commercially sensitive. Trotter (1996) confirms this point for the post-liberalization UK. He states in his conclusion that UK work has been hampered by a relative lack of data, partly due to technical reasons, and partly due to most of the UK market being supplied by one monopoly supplier, which makes any cross-section analysis difficult. While we tried to remedy the latter point in this article, we agree with the above observations. There remains a need for further work as an input into UK policy decisions. More detailed work is however likely to depend on the data being specifically collected, as has been the case for several of the main US studies.

References

Alleman, J. (1977) The pricing of local telephone service, OT Special Publications 77-14, Office of Telecommunications, U.S.Department of Commerce, Washington, DC.

Browning, M., Deaton, A. and Irish, M. (1985) A profitable approach to labor supply and commodity demands over the life-cycle. Econometrica 53(3), 503-543.

Cain, P. and Macdonald, J. (1991) Telephone pricing structures: The effects on universal service. Journal of Regulatory Economics 3, 293-308.

Cracknell, D. (1982) Price Elasticity of Demand for UK Telephone Calls. Economics Advisory Division, BT Headquarters, London.

Cracknell, D. (1988) The Analysis of Growth in Demand for Access- A Disaggregated Approach. Economics Advisory Division, BT Headquarters, London.

Cracknell, D. and Knott, M. (1995) The measurement of price elasticities - the BT experience. International Journal of Forecasting 11, 321-329.

Cracknell, D. and White, D. (1989) The Use of Panel Data in Market Analysis - BT's Experience. Economics Advisory Division, BT Headquarters, London.

Davis, B., Caccappolo, G. and Chaudry M. (1973) An econometric planning model for American Telephone and Telegraph Company. Bell Journal of Economics and Management Science 4(1), 29-56.

Deaton, A. (1985) Panel data from times series of cross-sections. Journal of Econometrics 30, 109-126.

Feldman, J. (1976) A preliminary cross sectional analysis of services. Unpublished paper, ATT.

Kirdel, D. and Taylor, L. (1993) The demand for commodity packages: The case of telephone custom calling features. Review of Economics and Statistics 75(2), 362-367.

Kirdel, D. (1988) A consumer surplus approach to predicting EAR development and stimulation rates. Information Economics and Policy 3(4), 379-390.

Moffitt, R. (1993), Identification and estimation of dynamic models with a time series of repeated cross-sections, Journal of Econometrics 59, 99-123.

OFTEL (1994) Households without a telephone. Office of Telecommunications, London.

Perl, L. (1978) Economic and Demographic Determinants of Residential Demand for Basic Telephone Service. National Economic Research Associates, Inc.

Perl, L. (1983) Residential Demand for Telephone Service 1983. Prepared for Central Service Organization of the Bell Operating Companies, Inc.BOCs, National Economic Research Associates,Inc., White Plains, NY.

Pousette, T. (1976) The Demand for Telephones and Telephone Services in Sweden. Presented at the European Meeting of the Econometric Society, Helsinki, Finland, August 1976.

Rash, I. (1971) An econometric model of demand for residential main telephone service. Bell

Canada Working Paper, Ottawa, Ontario.

Southern New England Telephone Company. Curtailment testimony of J. Jeske, Connecticut Docket No. 770526. June 27, 1977.

Taylor, L. (1980) Telecommunications Demand: A Survey and Critique. Ballinger, Cambridge, Mass.

Taylor, L. (1994) Telecommunications Demand in Theory and Practice. Kluwer, Dordrecht.

Taylor, L. and Kirdel, D. (1990) Residential demand for access to the telephone network. In A. DeFontenay, H. Shugard and D. Sibley (eds) Telecommunications Demand Modelling. North Holland Publishing Co, Amsterdam.

Train, K. (1994) Self-selecting tariffs under pure preferences among tariffs. Journal of Regulatory Economics 6, 247-264.

Train, K., Ben-Akiva, M. and Atherton, T. (1989) Consumption patterns and self-selecting tarifffs. Review of Economics and Statistics 71(1), 62-73.

Train, K., McFadden, D. and Ben-Akiva, M. (1987) The demand for local telephone service: A fully discrete model of residential calling patterns and service charges. The Rand Journal of Economics 18(1), 109-123.

Trotter, S. (1996) The demand for telephone services. Applied Economics 28, 175-184.

Trotter, S. (1989) The demand for telephone services. CRICT Discussion Paper, Brunel University.

Verbeek, M. (1992) Pseudo panel data. In L. Matyas and P. Sevestre (eds) The Econometrics of Panel Data: Handbook of Theory and Applications, Kluwer Academic Publishers, Dordrecht, 1992.

Verbeek, M. and Nijman, T. (1992) Can cohort data be treated as genuine panel data? Empirical Economics 17, 9-23.

Waverman, L. (1974) Demand for Telephone Services in Great Britain, Canada and Sweden. International Conference on Telecommunications Economy, University of Acton, Management Center, May 29, 1974.

Wenders, J. (1987) The Economics of Telecommunications: Theory and Policy. Harper and Row.