Australian telephone network subscription and calling demands: evidence from a stated-preference experiment

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This paper examines the impact of the subscription-calling rate structure on the demand for residential telephone network subscription and calling. Stated-preference experimental data are used to estimate demand equations. The results indicate that household network subscription and calling demands for the Sydney Metropolitan Area are affected by both rate structure and household socio-demographic variables.

Keywords: Telecommunications demand; Subscription-calling rate structure; Stated-preference experimental analysis; Survey

JEL Classification: D12; L96

1. Introduction

The Australian telecommunications subscription-calling rate structure has developed in a monopolistic environment. Cross-subsidies in the rate structure have contributed to pressure for a competing telecommunications

carrier to encourage the market provision of an optimal (efficient) rate structure.[1] A major problem for carriers in designing optimal rate structures is that little is known of consumer subscription-calling response to changes in prices.

Previous studies of residential telephone demand (Mitchell, 1978; Pacey, 1983; Park et al., 1983; Taylor and Kridel, 1990) separately explain regional call traffic revenues and telephone network penetration rates in terms of regional income and call-price indices.[2] These studies ignore the interdependence of individual telephone network subscription and telephone calling demands as established by Squire (1973). Further, the effects of variables that carriers control, such as the rate structure over calling distance or timing of calls, are excluded from the analyses. Any temporal call substitution that may exist is ignored.

A framework is developed in the present paper for conducting telecommunications stated-preference (or conjoint) pricing experiments to enable the evaluation of consumer response to alternative rate structures and determine the associated expenditure. Building on the notion that household telephone calling demand is a vector of call-minutes corresponding to separately priced distance-time bands, stated-preference methods provide a set of experimental call-minute price regimes. Survey respondents specify conditional household call-minute demands corresponding to a price vector generated by a fractional factorial experiment applied to the set of experimental price regimes. After specifying the conditional demands the respondent then indicates whether household network subscription is maintained at the experimental line rental charge.

The paper is organised as follows. The received telephone demand theory is described and extended to the vector case in Section 2. In Section 3, the estimable model and econometric method are specified. Section 4 provides a description of the stated-preference data generation method and the survey procedures. A discussion of the estimation results is provided in Section 5.

2. The model

The demand for telephone network subscription and calling is jointly determined. In this section the received theory (Squire, 1973) is extended to the individual choice of subscription level and calling portfolio. An

[1] On 8 November 1990 the Australian Government announced its decision to establish a private sector competitor (Optus Communications) to a merged Telecom/OTC (AOTC) in the provision of network facilities.

[2] Several recent attempts model the demand for residential service choice and the demand for local calling use cross-sectional micro-level survey data (e.g, Kling and Van Der Ploeg 1990; Atherton et al., 1990; Train et al., 1987).

econometrically testable model consistent with the extended formulation is specified by linking the model to a continuous/discrete choice framework.

2.1. Received theory

Consider a telephone network that serves an area populated by N households. Each household faces a discrete network subscription decision and a choice of how many fixed price telephone calls to make. Assume household i utility is a function of the number of calls made (q) and amount of other goods (x) consumed,

$$u_i = u_i(q, x),\tag{1}$$

where q takes the value 0 (no network subscription) or >0 (single line rental network subscription) and x is an n-dimensional vector. Utility is assumed strictly quasi-concave in q and x.

Because the subscription choice can involve a corner solution, the problem is formulated as a two-stage process. The household is assumed to select a subscription alternative. Values of q and x are then chosen to maximise (1) subject to the household budget constraint,

$$px + \delta(r + p_c q) = y_i,\tag{2}$$

where p is a vector of prices for other goods, r is the line rental (subscription) fee, p_c is the price per call and y_i is household i money income. The parameter $\delta = 1$ if the household subscribes to the network; $\delta = 0$ otherwise.[3]

The utility maximisation problem for any household implies a maximum value of the subscription fee r_i^* that leaves the household indifferent as to whether to subscribe. Solving explicitly for r_i^*,

$$r_i^* = \psi_i(p, p_c, y_i),\tag{3}$$

provides the subscription reservation-price function for household i. Assuming that free subscription is preferred to no network access, $0 < r_i^* \leq y_i$. ψ_i is homogeneous of degree one in p, p_c and y_i under the assumption that $v_i(p, p_c, y_i - r_i^*)$ is homogeneous of degree zero.

Suppose r_i^* varies according to some probability density $h(r_i^*)$. If r is the single line rental subscription fee then household i subscribes if and only if $r_i^* \geq r$. Denote N_1, the number of telephone subscribers in the population.

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[3] If $\delta = 0$ then $q = 0$. That is, if the household decides not to access the network then no calls are made.

Telephone network subscription penetration, $n = N_1/N$, is

$$n = \int_r^\infty h(r_i^*)\, dr_i^* .\tag{4}$$

Further, assume the distribution of reservation prices is

$$\log r_i = \phi(p, p_c, \bar{y}) + \varepsilon_i ,\tag{5}$$

where ε_i is distributed extreme value with mean equal 0 and variance equal σ^2.[4] Then $\log r_i^*$ is distributed logistic with mean $\phi(p, p_c, \bar{y})$ and variance σ^2. The probability density is

$$h(Z^*) = \frac{\exp(Z^*)}{\tau[1 + \exp(Z^*)]^2} ,\tag{6}$$

where $Z^* = [\log r_i^* - \phi(p, p_c, \bar{y})]/\tau$ and $\tau = \sqrt{3}/\pi$. With subscription fee r charged, the penetration rate is

$$n = \text{prob}\,(r_i^* \geq r)$$

$$n = \int_Z^\infty h(Z^*)\, dZ^*$$

$$= \frac{1}{1 + \exp(Z)} ,\tag{7}$$

where $Z = [\log r - \phi(p, p_c, \bar{y})]/\tau$.

2.2. Received theory: an extension

The received theory establishes the interdependence of telephone network subscription and calling demand in that household subscription-calling decisions are influenced by both the price per call and the line rental charge. However, the choice set is unduly restricted. Here the choice set is expanded in two ways. First, the line rental alternatives include no network subscription, single line rental subscription, subscription with two rental lines and so on. Second, the individual chooses a number of call-minutes $(m_{ij}^{d,t})$ in several distance-time bands, so that his calling portfolio is defined as a particular number of call-minutes for each distance-time calling band.

Formal derivation of the extended model follows Dubin and McFadden

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[4] In general households differ both in income and preferences. To illustrate how the presented theory can generate logit probabilities we assume $y_i = \bar{y}\ \forall_{i \in N}$. We could have just as easily assumed identical preferences with household income distributed logistically.

(1984) and Dubin (1985). Household i faces the set J of mutually exclusive, exhaustive subscription alternatives. Subscription alternative j has a line rental fee, r_j, with $r_0 = 0$. Label the observed characteristics of each alternative j in J as z_j^0, household income as y_i, other observed characteristics of the household as s_i^0, and all unobserved factors as w_{ij}. The call-minute price, denoted as $p_c^{d,t}$, is an element of the call-minute price vector p_c.

The maximum attainable utility for alternative j in J is given by

$$v_{ij} = v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij}) . \tag{8}$$

The household selects alternative j if and only if

$$v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij})$$
$$> v_{ik}(p_c, y_i - r_k, z_k^0, s_i^0, w_{ik}) , \quad \forall_{k \in J}, k \neq j . \tag{9}$$

The corresponding choice probability for alternative j is

$$P_{ij} = \text{Prob}[v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij})$$
$$> v_{ik}(p_c, y_i - r_k, z_k^0, s_i^0, w_{ik}) \quad \forall_{k \in J}, k \neq j] . \tag{10}$$

To specify closed-form probabilities requires that indirect utility is partitioned as follows:

$$v_{ij} = v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0) + e_{ij} , \tag{11}$$

where $e_{ij} = e_{ij}[w_{ij}(z_j^u, s_i^u)]$. v_{ij} is the representative indirect utility of household i for alternative j.[5] With e_{ij} distributed extreme value, the closed-form subscription probabilities are logit in v_{ij} such that

$$P_{ij} = \frac{\exp[v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0)]}{\Sigma_{k \in J} \exp[v_{ik}(p_c, y_i - r_k, z_k^0, s_i^0)]} . \tag{12}$$

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[5] The MNL model in (11) differs from the reservation price model in (5) in the rationale for e_{ij}. In the MNL model individuals differ only in their personal characteristics and the importance they place on an alternative's characteristics. Individuals do not differ in the manner in which they substitute between characteristics, that is, individuals share the same parameterisation of utility. In this case e_{ij} represents unobserved factors (to the analyst) in each trial. The reservation price model places no such restrictions on individual behaviour. With all individual and product characteristics observed, e_{ij} reflects differences in the shape of the individual utility surface. When the distribution over the economy of unobserved characteristics coincides with that of utility surfaces, penetration rates will coincide.

The demand for $m_{ij}^{d,t}$ is determined from the conditional indirect utility functions using Roy's identity. That is:

$$m_{ij}^{d,t} = - \frac{\partial v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij})/\partial p_c^{d,t}}{\partial v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij})/\partial(y_i - r_j)}$$

$$= m_{ij}^{d,t}(p_c, y_i - r_j, z_j^0, s_i^0, w_{ij}) . \tag{13}$$

The conditional demands in (13) depend both on observed and unobserved factors.

3. Econometric method

The subscription-calling demand system [(12), (13)] is operationalised by separating representative and random utility as in (11). The equation (13) error structure depends on how w_{ij} enters $m_{ij}^{d,t}$. Random utility is assumed distributed extreme value, while the arguments and a mathematical form of representative utility and the call demand equations are specified below.

3.1. Econometric model specification

Decomposition of the indirect utility through (11) provides the subscription probabilities,

$$P_{ij} = \text{Prob}[e_{ik} - e_{ij} < v_{ij}(p_c, y_i - r_j, z_j^0, s_i^0)$$

$$- v_{ik}(p_c, y_i - r_k, z_k^0, s_i^0) \quad \text{for } k \neq j, k = 0, \ldots, J] , \tag{14}$$

and implies that the calling demands obtained through (13) are of the form:

$$m_{ij}^{d,t} = m_{ij}^{d,t}(p_c, y_i^0 - r_j, z_j^0, s_i^0) . \tag{15}$$

The continuous/discrete demand specification (14, 15) requires that the explicit functional forms for call-minute demands and indirect utility are compatible, because v_{ij} and $m_{ij}^{d,t}$ are connected through (13). The search for an eligible utility model is further restricted by the maintained hypothesis employed in continuous/discrete demand models, that discrete alternatives are mutually exclusive goods.

Dubin (1985) satisfies the conditions in solving linear durable utilisation demands to find the compatible indirect utility function as follows:

$$v(p_1, \ldots, p_n, y) = [\exp(-\Sigma \beta_j p_j)] \cdot [y + M(p_1, p_2, \ldots, p_n)] , \tag{16}$$

where

$$M = \int_{p_1} \exp(\beta_1(p_1 - t)) \cdot M_1(t, p_2, \ldots, p_n) \, dt \,, \tag{17}$$

satisfies Slutsky symmetry restrictions:[6]

$$\beta_j M - \frac{\partial M}{\partial p_2} = M_j \quad \text{for } j = 1, 2, \ldots, n \,. \tag{18}$$

Here call-minute demands (15) are considered in a system where $m_{ij}^{d,t}$ is linear in $(y_i - r_j)$, alternative j characteristics and household i characteristics, viz.,

$$m_{ij}^{d,t} = M_{ij}(\boldsymbol{p}_c) + \beta_{ij}(y_i - r_j) + f(z_j^0, s_i^0) \,, \tag{19}$$

where M_{ij} and f are vector-valued functions and β_{ij} is a scalar parameter.

A special case of the indirect utility function considered by Dubin and McFadden (1984) and Train (1986),

$$\begin{aligned} v_{ij} = \ln[&(\alpha_{ij} + \boldsymbol{\theta}_{ij}\boldsymbol{p}_c + \beta_{ij}(y_i - r_j) \\ &+ \psi_{ij} f(z_j^0, s_i^0) \cdot \exp(-\beta_{ij} p_c^{d,t})] \,, \end{aligned} \tag{20}$$

provides the call demands:

$$\begin{aligned} m_{ij}^{d,t} = &[\alpha_{ij} - (\theta_{ij}/\beta_{ij})] + \boldsymbol{\theta}_{ij}\boldsymbol{p}_c + \beta_{ij}(y_i - r_j) \\ &+ \psi_{ij} f(z_j^0, s_i^0) + e_{ij} \,. \end{aligned} \tag{21}$$

There is no variation in $\beta_{ij} p_c^{d,t}$ over (i, j), so household i ignores the value in comparing v_{ij} and v_{ik}. Therefore, the probability that household i subscribes j rental lines is,

$$P_{ij} = \text{Prob}(v_{ij} + e_{ij} > v_{ik} - e_{ik} \quad \text{for all } k \text{ in } J, k \neq j) \,, \tag{22}$$

where $v_{ij} = \alpha_{ij} + \boldsymbol{\theta}_{ij}\boldsymbol{p}_c + \beta_{ij}(y_i - r_j) + \psi_{ij}(z_j^0, s_i^0)$.

Economic theory suggests call demands (15) vary with the $p_c^{d,t}$ in $\boldsymbol{p}_c$. Because within a distance band temporal call substitution is plausible, the magnitude of the cross price elasticities need to be determined. However, for convenience call substitution over other distance bands is assumed

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[6] Additional integrability restrictions (homogeneity, summability, non-negativity, and negative quasi-semi-definiteness) are imposed on M by the requirement that $v(p_1, p_2, \ldots p_n, y)$ be an indirect utility function.

implausible, and variation in their price acts through the budget constraint. Equations (21) are specified,

$$m_{ij}^{d,t} = \gamma_{ij}^{d,t} + \sum_t \theta_{ij}^{d,t} \, p_c^{d,t} + \beta_{ij}^{d,t}(y_i - r_j) + \psi_{ij}^{d,t} \, \bar{f}(s_i^0) + e_{ij}^{d,t} \,, \tag{23}$$

where d and t refer to five distance bands and three time zones, respectively.[7]

3.2. Sequential econometric estimation method

The random drawing of (j, m, s) combinations from the joint distribution of telephone line rental choice, household calling and household characteristics define the sample likelihood,

$$\mathscr{L}^*(\theta) = \prod_\tau \prod_m \prod_j f(j, m, s)^{y_{\tau j}} \,, \tag{24}$$

where $f(j, m, s)$ is the joint distribution of the telephone choice experiment responses and household characteristics in the single telephone line market segment, while the $(0, 1)$ variable $y_{\tau j}$ indicates the number of telephone lines rented by household i in trial repetition τ. The joint distribution of experimental choices and household characteristics are decomposed as follows:

$$
\begin{aligned}
f(j, m, s) &= P(j \mid m, s, \boldsymbol{\theta})p(s) \\
&= P(j \mid m(s), s, \boldsymbol{\theta})p(s) \\
&= P(j \mid s, \boldsymbol{\theta})p(s).
\end{aligned}
$$

The associated log likelihood function,

$$
\begin{aligned}
\mathscr{L} &= \sum_\tau \sum_j y_{\tau j} \ln P(k \mid s_\tau, \boldsymbol{\theta}) + \sum_\tau \ln p(s_\tau) \\
&= \sum_\tau \sum_j y_{\tau j}\left(\boldsymbol{\theta}^T s_{\tau j} - \ln \sum_j \exp(\boldsymbol{\theta}^T s_{\tau j})\right) + \sum_\tau \ln p(s_\tau) \,, \tag{25}
\end{aligned}
$$

for linear-in-parameters logit choice probabilities. McFadden (1974) proves

[7] The following distance-time calling bands are used for the empirical analysis: Day, 0–10 km; Night, 0–10 km; Day, 10–30 km; Night, 10–30 km; Day, 30–100 km; Night, 30–100 km; Economy, 30–100 km; Day, 100–800 km; Night, 100–800 km; Economy, 100–800 km; Day, Over 800 km; Night, Over 800 km; Economy, Over 800 km. The Over 800 km time zones are 8 am through 6 pm Monday through Saturday, 6 pm through 10 pm Monday through Friday and 10 pm through 8 am everyday and 6 pm Saturday through 8 am Monday, respectively.

that $\mathscr{L}$ is globally concave in $\boldsymbol{\theta}$ and that the ML estimator $\boldsymbol{\theta}$ is consistent and asymptotically normal.[8]

The five distance bands and three time zones define thirteen intra-Australian distance-time calling bands. Thirteen estimable subscription conditional call minute demand equations are associated with the discrete option of subscription with single line rental. Estimating the conditional calling demand equations separately using OLS or when grouped by calling time and distance band using a systems method, provides biased and inefficient parameter estimates. The selection bias arises from unobserved factors that influence both the household line rental choice and household calling pattern decisions. Formally, the expectation of the random error term in the (d, t)th calling demand equation, conditioned on the event that k lines are rented, is not zero,

$$E(e_{ik}^{d,t}) = E(e_{ij}^{d,t} \mid j = k) \neq 0 , \qquad (26)$$

for all j, k in J. The random error term in (d, t)th calling demand is decomposed,

$$e_{ik}^{d,t} = E(e_{ij}^{d,t} \mid j = k) + \eta_i^{d,t} , \qquad (27)$$

where $E(\eta_i^{d,t}) = 0$ and $\operatorname{correl}(\eta_i^{d,t}, E(e_{ij}^{d,t} \mid j = k)) = 0$.

Unbiased conditional calling demand equation parameter estimation follows from applying the conditional expectation correction to either separate OLS estimation of household calling demand equations on the subsample that choose to rent k lines, using,

$$E(e_{ij}^{d,t} \mid j = k) = \sum_{\substack{j \in J \\ k \neq j}}^{J} \left[\frac{\sigma \sqrt{6} R_{ij}}{\pi} \right] \left[\frac{P_{ij} \ln P_{ij}}{1 - P_{ij}} + \ln P_{ik} \right] , \qquad (28)$$

as a consistent estimate for $E(e_{ij}^{d,t} \mid j = k)$ or by applying SUR estimation to calling demand equations on the entire sample. SUR estimation of the equations is more efficient than OLS applied separately to the conditional calling demand equations because cross-equation disturbance correlation is present. The correlation between disturbance terms over other distance bands arises from price variations affecting other calling demands through the budget constraint.

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[8] Computational efficiency is lost when ML methods are applied to data assuming each observation is separate, when each individual is observed repeatedly while attributes of alternatives remain constant. Ben-Akiva and Lerman (1985) detail computationally efficient weighted ML procedures. The procedures are not appropriate here because although each individual is observed repeatedly, attributes of alternatives and the alternatives themselves vary across choice sets.

4. Experimental data generation and sampling methods

Parameter estimation requires paired household subscription-calling and rate data. These data are not available by distance-time band and stated-preference experimental data is used as an alternative data source. Details of the experimental data generation method, survey procedure and questionnaire design used in data collection is now outlined.

4.1. The stated-preference and experimental design methods

Stated-preference experiments define alternatives as collections of observed characteristics. Changing the level of some characteristic generates another alternative. The method requires households select the preferred alternative from a choice set of nondominant alternatives. An experiment is identified by the characteristics of the alternatives, the number and magnitudes of characteristic levels, the number of replications households' face, and the conjoint choice set generation process specified.[9]

Estimation of continuous/discrete models using stated-preference data requires that the experimental design, or at least the observation submatrix subject to the experimental design, is optimal for both the discrete choice and continuous models. Louviere and Woodworth (1983) establish a sufficient condition for parameter estimation of IIA (GEV and MNL) choice probabilities, that alternatives are pairwise independent (or orthogonal) across choice sets. Aigner (1979) and Conlisk (1973) demonstrate, for the linear and additive econometric regression model with an intercept, that mutual orthogonality among regressors is an optimal design plan.[10] Subject

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[9] More complex designs lead individuals to use simpler lexicographic non-trading choice rules. When a full factorial design generates a large number of choice sets the number is reduced by adopting a fractional factorial design. Fractional set design output is a minimum size incidence matrix (choice sets × alternatives) that enables full parameter estimation.

[10] The precision matrix for the model estimates is:

$$(\sigma^2/n)M_{xx}^{-1}$$

where

$$M_{xx} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & m_{11} & m_{12} \\ 0 & m_{21} & m_{22} \end{bmatrix}.$$

and

$$m_{ij} = (1/n) \sum_{t=1}^{n} (m_{ti} - \bar{m}_{ti})(m_{tj} - \bar{m}_{tj}).$$

Best estimates are obtained by applying the rule,

$$\max \det M_{xx} \Leftrightarrow \min \det \frac{(\sigma^2)}{n} M_{xx}^{-1}$$

referred to as D-optimality.

to asymptotic approximation, Conlisk (1979) extends the optimal design criterion to the simultaneous equation model. Main-effects fractional factorial plans with symmetric orthogonal arrays provide the most parsimonious set of designs under which the continuous/discrete model optimality conditions apply to both the MNL and SUR estimators.

4.2. An experimental calling rate structure set design for Australian telephone demand

Conjoint methods provide the set of calling rate structures, the call-minute price submatrix of the observation matrix for the calling demand system, from the set of experimental price levels. Separately priced distance-time calling bands with three call-minute price levels (high, medium, low), define 3^{13} different calling rate structures.[11] All possible calling rate structures are represented by a 3^{13} full factorial design. Catalogue fractional factorial designs generate a matrix comprised of orthogonal calling rate structures. However, the method does not necessarily provide a spread of call-minute levels across rate structures that is diverse. A 16 treatment-combination design is selected from the 3^{13} full factorial design by taking repeated random samples from the design with a random seed. The selected design represents a trade-off between the degree of orthogonality, dominance and a reasonable spread of call-minute price levels across rate structures.

The stated-preference experiment requires that households specify a preferred calling portfolio for some conjoint-generated calling rate structure. The household is informed of the calling expenditure 'incurred' under

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[11] The following low, medium and high call-minute prices are used in the survey:

Experimental call-minute prices (cents/minute)			
Day 0–10 km	12	8	6
Night 0–10 km	6	4	2
Day 10–30 km	15	11	9
Night 10–30 km	9	7	3
Day 30–100 km	23	17	14
Night 30–100 km	14	11	8
Economy 30–100 km	8	7	4
Day 100–800 km	44	36	30
Night 100–800 km	30	24	19
Economy 100–800 km	19	14	7
Day over 800 km	66	57	48
Night over 800 km	48	38	28
Economy over 800 km	28	23	16

the experiment and allowed to adjust the stated demands. The household is required to indicate whether network subscription is maintained at the experimental line rental charge.[12] The experiment is repeated three times, the replications correspond to different calling rate structures.

4.3. Survey procedure and questionnaire design

These data are assumed generated by the trial of drawing a household at random from the single line telephone rental market segment of the population and recording the household's characteristics, experimental subscription-calling choice and the corresponding rate structures.[13] The sampling rule requires that a sequence of three independent trials, experimental calling rate structures, is presented to households renting a single line. The trial outcome is a (j, m) pair chosen by the household from $J \times M$, the incidence space.[14]

A predetermined sample size of 175 households (700 cases, three in-

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[12] The following quarterly line rental fee options are used in the survey

Experimental line rental fees ($/quarter)

Low cost band	15	20	25	30	35
Medium cost band	40	45	50	55	60
High cost band	65	70	75	80	85

[13] Household characteristics capture the behavioural factors conditioning household choices. Telecom Australia Telephone Ownership surveys indicate the following households characteristics are useful to this study: (1) Number of residents in the household; (2) Number of workers in the household; (3) Home owned or paying rent; (4) Length of residence; (5) Ethnic origin of head of household; (6) Sex of head of household; (7) Age of head of household; (8) Occupation of head of household; (9) Employment status of head of household; (10) Years of schooling of head of household; (11) Self-employed or salaried head of household; (12) Telephone use subsidised or not.

[14] Telecom indicate the percentage of households not subscribed in the Sydney Metropolitan Area is approximately 5 percent, while the percentage of homes with multiple telephone line access is around 3 percent. The latter figure can be treated as an overstatement when allowance is made for the business calling on lines rented for residential use. The procedure used here is to redefine the universe and consider only the calling and line rental behaviour of the dominant single telephone line rental sector of the telephone line rental market. Modelling the single line market separately does require a reinterpretation of the estimating equations. The probability that a sampled household chooses single line subscription is interpreted as the likelihood that a currently single line subscribing household maintains subscription at experimental prices. The associated call minute demand equations for 0–10 km day calling is interpreted as the call demand for 0–10 km day calling by households that choose to retain subscription at experimental prices. Similar interpretations apply to other experimental subscription decisions and conditional calling demand equations.

dependent trials and the base case for each household) is sampled by an exogenous stratified random sampling method. The stratification is by postcode number on the basis of socio-demographic characteristics. Sampling within each postcode area is by a simple random draw from the telephone directory. Households in the postcode area are contacted by telephone to arrange an appointment for interview.

The stated-preference experiment is implemented so as to obtain reasonable household experimental calling responses by controlling the experimental conditions. The experiment is controlled by first determining the households' current calling portfolio, evoked set, and then by presenting the household with rate structures only for currently called distance bands. Zero call demand is recorded for the distance bands not called in the households' current calling portfolio.[15]

The approach causes the number of zero cases to dominate the number of positive cases in the dependent call demand vector for the over 30 km calling demands. For example, positive household demand for day calling to the Over 800 km calling band is reported for only 40 of the 700 cases.

5. Results

The telephone line-rental model provides the probability that a household will subscribe to the telephone network by renting a telephone line. The subscription probability, in (22) assumes the household has a binary choice of renting a line. The probability depends on factors that reflect the household's utility from telephone services and its ability to pay for the services. Socio-demographic variables are included in the estimating equation to capture factors that influence the utility derived from telephone services. Besides the household income variable, other socio-demographic variables entered in the line-rental equations include, the total number of persons (HHSIZE), the number of children under 14 years (AGE014), and the number of persons aged between 15 and 24 years residing in the household (AGE1524). Also included are dummy variables indicating whether the home is owned (HOMEOWN), the residence has been rented for less that one year (MOVERS), the head of household is the sole resident (SINGLE), the head of household is currently unemployed (UNMPLOY), the head of household is aged less than 25 years (HEADU25), the head of household is aged between 25 and 34 years (HEAD2534), the head of household is aged between 35 and 44 years (HEAD3544), the head of

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[15] The assumption underlying the method is that households call bands where a calling population of known previous contacts is resident, irrespective of the calling rate structure. However, call frequency or duration are reduced in the face of a higher call price. If the assumption is incorrect, estimated price elasticities understate the true elasticities.

Table 1
Household telephone calling frequency.

Distance-time calling band	Household average quarterly call demand (minutes)	Households with non-zero demands (maximum 700)
Day 0–10 km	856.3	626
Night 0–10 km	633.6	591
Day 10–30 km	304.8	497
Night 10–30 km	239.9	487
Day 30–100 km	77.4	132
Night 30–100 km	50.3	189
Economy 30–100 km	7.8	65
Day 100–800 km	30.7	100
Night 100–800 km	74.1	267
Economy 100–800 km	25.0	118
Day over 800 km	21.5	40
Night over 800 km	18.5	96
Economy over 800 km	9.2	56

household is aged between 45 and 54 years (HEAD4554), and the head of household is aged between 55 and 64 years (HEAD5564).

The elasticities of the line-rental probability with respect to call-minute prices and income are provided in Table 2 below. The signs of the line rental probability elasticities for the call-minute prices are negative for nine of the call-minute prices. All the estimates are inelastic and small in magnitude.

Table 2
Line rental call-minute price and income elasticities.

D10	−0.003*
N10	−0.0003
D30	0.0004
N30	0.0001
D100	−0.002**
N100	−0.0007
E100	0.003**
D800	−0.0008
N800	0.002
E800	−0.0001
D801	−0.003
N801	−0.003**
E801	−0.001**
INCOME	0.0002*

* Parameter is significant at the 5% level.
** Parameter is significant at the 10% level.

Except for the day 0–10 km call-minute price, the absolute values of the *t*-ratios are less than two. The sign for the subscription probability income elasticities is positive, while the *t*-ratio is in excess of two.

Regarding the socio-demographic factors, none of the parameters are individually significantly different from zero at the 5 percent level. However, the likelihood ratio test for the joint hypothesis that the socio-demographic variables as a group do not add sufficient explanatory power to the model to compensate for the degrees of freedom utilised by the fuller specification is rejected at the 5 percent level. The model correctly predicts 96 percent of household subscription choices.

The calling demand equations are jointly estimated as a SUR system to allow for the cross-equation correlation caused by the household wealth constraint. Both the economic variables and socio-demographic variables specifications assume calling substitution between distance bands is implausible. The prices that matter to the household in determining a distance-time band quarterly calling demand is the call-minute price for the distance-time band and the call-minute prices for the same distance band but other time zones. Tables 3 and 4 below present the calling own and cross-price elasticity estimates for the socio-demographic variables specification of the model. Full results for this specification are shown in Appendix Table 1.

The own-price elasticities suggest that 0–30 km calling is price inelastic. Cross-price elasticities are smaller in magnitude than own-price elasticities for corresponding distance bands.

For over 30 km calling the negatively signed own-price elasticity estimates increase in magnitude with distance called. Economy Over 800 km calling is own-price elastic. Unlike the 0–30 km calling estimates there is no clear pattern suggesting cross-price elasticities are smaller than own-price elasticities.

The positively signed calling income elasticities provided in Table 5 above are inelastic. The negatively signed economy calling equations estimate supports the proposition that economy calls are regarded as an inferior good by subscribers.

Table 3
0–30 km calling demand call-minute price elasticities.

Distance-time calling band	D10	N10	D30	N30
Day 0–10 km	0.05	0.04	–	–
Night 0–10 km	−0.01	−0.23	–	–
Day 10–30 km	–	–	−0.40	0.16
Night 10–30 km	–	–	−0.06	−0.46*

* Parameter is significant at the 5% level.

Table 4
Over 30 km calling demand call-minute price elasticities.

Distance-time calling band	D100	N100	E100	D800	N800	E800	D801	N801	E801
Day 30–100 km	−0.53	0.03	−0.30	–	–	–	–	–	–
Night 30–100 km	−0.59	0.67	0.82*	–	–	–	–	–	–
Economy 30–100 km	1.04	−0.35	0.47	–	–	–	–	–	–
Day 100–800 km	–	–	–	−0.64	0.50	−0.05	–	–	–
Night 100–800 km	–	–	–	0.21	−0.21	0.18	–	–	–
Economy 100–800 km	–	–	–	−0.09	0.59	0.14	–	–	–
Day Over 800 km	–	–	–	–	–	–	−0.82	−2.08	−0.34
Night Over 800 km	–	–	–	–	–	–	−0.59	−0.61	−0.30
Economy Over 800 km	–	–	–	–	–	–	−0.12	−0.74	−1.01

* Parameter is significant at the 5% level.

Table 5
Calling demand income elasticities.

Day 0–10 km	0.46*
Night 0–10 km	0.25
Day 10–30 km	0.24
Night 10–30 km	−0.08
Day 30–100 km	0.23
Night 30–100 km	0.03
Economy 30–100 km	0.33
Day 100–800 km	0.47
Night 100–800 km	0.90*
Economy 100–800 km	−0.32
Day over 800 km	0.28
Night over 800 km	0.95*
Economy over 800 km	−1.06*

* Parameter is significant at the 5% level.

The coefficients of the socio-demographic variables model represent the partial effect of each variable on household calling. For example, Park et al. (1983) and Kling and Van Der Ploeg (1990), study the effect of demographic variables on household local calling under a measured rate regime. The results of the studies regarding signs for the estimated coefficients are that large households reduce their calling relative to smaller households, that is, the number of persons resident in the household (HHSIZE) has a negative impact on local calling. However, given this effect an increase in the number of children and young adults resident in the household results in a greater demand for local telephone calls. The coefficients for the number of children resident in the household (AGE014) and the number of persons aged between 15 and 24 years resident in the household (AGE1524) are positive.

The results reported in Appendix Table 1 indicate that larger households have lower calling demands in 69 percent of the calling equations. The number of negatively signed coefficients is evenly spread over the five distance bands. The proportion of negatively signed coefficients is greatest for the day and night calling zones. Negatively signed coefficients are more often significant in the 0–30 km calling equations.

Day calling demand is lower for renting households that have recent tenure. There is no clear distance related pattern for the negatively signed coefficients.

Calling is greater in the region for households where the home is owner occupied. 77 percent of the estimated coefficients are positively signed in the equation. Day and night calling have 80 percent of the home ownership dummy variable coefficients positively signed.

The impacts on household calling demands of resident children and

young adults resident are similar, with 77 percent of the estimated co-
efficients in the calling systems positively signed. 0–30 km calling is greater
for the region with all of the estimated coefficients positively signed. Night
calling volume is significantly greater when children are resident. Resident
young adults significantly increase household local calling demand. Night
and economy calling equations have 75 percent of the estimated coefficients
positively signed while the day calling have 40 percent of the estimated
coefficients positively signed.

Calling demands are smaller for households with a head under 25 years of
age relative to those with head over 65 years for all the regions. The pattern
holds for all calling distance bands. No general pattern is evident concerning
the calling demands for households for other age heads relative to those
with over 65 years of age heads.

A nested test of the economic and socio-demographic variable model
specifications is made. The test rejects the joint hypothesis that the parame-
ters of the socio-demographic variables are simultaneously zero, at the one
percent level. The F-test performed is valid only for OLS, given the
customary assumptions of the linear model. However, the test has good
asymptotic properties for other estimation procedures including SUR.

Correlation between the household network subscription choice dummy
variable and the random error term in the calling demand equations arises
when unobserved factors influence both the household network subscription
choice and the household calling demands. The problem is that the expecta-
tion of the disturbance term in the calling demand equations is not zero for
each observation. This problem is addressed by including a selectivity
correction variable in the calling demand equations to force the expectation
of each disturbance term observation to zero. The proposition that subscrip-
tion demand and calling demand for a particular distance-time band are
interdependent is supported when the estimated coefficient on the selectivity
correction variable is significantly different from zero. The structure of
subscription and calling demand system interdependence is best observed by
examining the pattern of significance for the correction variable through the
calling demand system. The selectivity correction terms vary in significance
by call distance. The 0–30 km call demand equations are associated with
negative and significant selectivity coefficients for the endogeniety of line
rental. Only 0–10 km night calling reveals no significant relationship be-
tween network use and the selectivity term, while calling for all distance
bands over 30 km is not significantly related to the correction term.

Application of the Breusch-Pagan test to the OLS results rejects the
homoskedasticity assumption in the calling demand equations. The standard
errors of the estimated parameters are generally reduced using White's
correction for heteroskedasticity. However, the changes in standard errors
lead on average to a change in the significance category for only one

estimated coefficient per equation. There is no clear pattern of change in significance by distance band.

A Wald test rejects the normality hypothesis for the regression residuals at the five percent level of significance. A subsequent examination of the standardised residuals indicates an average five percent of the residuals exceed two in absolute value, indicating possible outliers. In the absence of normality, small-sample tests of hypotheses developed using normality are no longer valid. However, t- and F-tests are asymptotically valid if the errors are independent and identically distributed with zero mean and finite variance. Further tests for functional form misspecification carried out indicate the test is significant for some of the equations.[16]

Another qualification about the reasonableness of the estimated parameters is that household call traffic is a decreasing function of distance. A minimum 25 percent of households report calling to the 0–10 km, 10–30 km, 30–100 km and 100–800 km distance bands for each time zone, whereas calling is reported by less than 10 percent of the respondent households for the Over 800 km distance band.

6. Conclusions

Estimates of the impact of price, income and socio-demographic variables on line-rental and call-minute demand provide insights for telecommunications planning and policy. Demand responsiveness to prospective income and socio-demographic trends aids planning for system capacity, while demand responsiveness to price provides information for determining the consequences of unregulated pricing.

The income elasticity for line-rental demand reported in Table 2 is positive as are most of the income elasticities for call-minute demand reported in Table 5. This suggests continued growth in telecommunications demand in Australia as household incomes grow. The exceptional negative income elasticities for call-minute demand occur in the night and economy time periods, suggesting attempts to shift calling demand to off-peak times are hampered by income growth.

Call-minute demand is generally inelastic with respect to own price in the estimates reported in Table 3 and Table 4. An unregulated monopolist faced with inelastic demand would find it profitable to raise prices. This suggests some form of regulation or competition is required if prices are to be kept within the range covered by the survey questions, a range that brackets

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[16] The equations and order of the Ramsey test rejected are as follows: Night, 0–10 km, second, third and fourth order terms; Economy, 30–100 km, third and fourth order terms; Day, 100–800 km, fourth order term; Night, 100–800 km, second, third and fourth order terms; Day, over 800 km, second and fourth order terms; Night, over 800 km, third and fourth order terms.

Appendix Table 1. Calling demand model parameter estimates

Explanatory variable	0–10 km Day	0–10 km Night	10–30 km Day	10–30 km Night	30–100 km Day	30–100 km Night	Economy
Constant	−390.571 (688.361)	−184.330 (503.761)	−138.829 (228.945)	−225.262 (209.619)	47.3906 (135.597)	96.2563 (49.7812)	21.5979 (13.3553)
D10	4.98641 (27.5295)	−0.51332 (21.3834)					
N10	7.26729 (33.6206)	−30.7996 (26.3856)					
D30			−10.5013 (8.88095)	−1.19701 (8.39678)			
N30			−6.60866 (10.3153)	−14.8484 (9.78797)			
D100				−2.26252 (2.50178)	−1.62450 (1.37059)	0.45099 (0.35948)	
N100				0.17772 (3.90253)	2.78921 (2.41682)	−0.222674 (0.63533)	
E100				−3.20191 (5.92823)	5.75391 (3.01617)	0.51304 (0.79198)	
D800							
N800							
E800							
D801							
N801							
E801							

INCOME	0.03919	0.01568	0.00734	−0.00191	0.00175	0.00015	0.00026
	(0.01442)	(0.01021)	(0.00522)	(0.00473)	(0.00339)	(0.00121)	(0.00032)
HOMEOWN	534.818	176.708	47.3071	200.462	43.8724	−7.12891	−18.7213
	(295.096)	(214.282)	(94.7719)	(86.0966)	(63.3866)	(24.2834)	(6.50130)
MOVERS	274.249	−192.396	−150.407	119.447	−16.0376	−39.9522	−16.2389
	(339.926)	(243.661)	(116.364)	(105.643)	(76.7857)	(28.3889)	(7.61507)
UNEMPLOY	329.356	846.474	−295.537	−400.885	90.7576	15.6750	−0.99916
	(413.916)	(296.532)	(141.919)	(128.816)	(93.3201)	(34.1196)	(9.15820)
HHSIZE	−322.433	−101.851	5.45433	−40.4207	4.53595	−19.7086	1.73225
	(135.759)	(96.0729)	(49.2864)	(44.7353)	(31.9074)	(11.3117)	(3.04174)
SINGE	−395.117	−40.8277	−17.4811	−59.6179	−103.262	−24.2510	−1.32553
	(244.963)	(173.252)	(89.0068)	(80.7764)	(57.7017)	(20.4461)	(5.49818)
AGE014	448.991	298.469	42.0731	93.8861	−30.5572	18.7844	1.05385
	(140.028)	(99.1044)	(50.7778)	(46.0863)	(32.8949)	(11.6622)	(3.13599)
AGE1524	475.091	634.150	87.5261	175.929	−41.1387	−0.63020	−4.44817
	(150.347)	(106.483)	(54.3473)	(49.3253)	(35.2875)	(12.5663)	(3.37818)
HEADU25	−624.370	−394.434	−78.2973	19.5060	39.8043	−17.7580	−8.28893
	(461.158)	(328.694)	(162.248)	(147.285)	(105.623)	(37.9643)	(10.2001)
HEAD2534	63.3164	306.147	177.706	385.350	40.1438	−1.10715	−4.50312
	(351.390)	(252.801)	(118.605)	(107.719)	(78.3252)	(29.2150)	(7.83290)
HEAD3544	424.863	185.070	233.368	318.398	44.0194	−17.3391	17.1146
	(321.817)	(231.352)	(108.995)	(98.9864)	(71.8021)	(26.6239)	(7.14051)
HEAD4554	415.787	220.331	197.805	216.827	141.238	−16.3898	−5.73007
	(313.276)	(224.994)	(106.321)	(96.5297)	(70.3684)	(26.1726)	(7.01830)
HEAD5564	636.050	308.005	260.815	295.707	145.898	−14.4526	−3.59891
	(313.644)	(225.180)	(106.894)	(97.0682)	(70.5110)	(26.1588)	(7.01554)
Correction	−78.7569	−39.6151	−22.7487	−25.5763	0.76546	3.79673	0.81415
	(33.1615)	(24.4638)	(9.68910)	(8.81070)	(6.7645)	(2.77502)	(0.74033)

Appendix Table 1 (*continued*)

Explanatory Variable	100–800 km			Over 800 km		
	Day	Night	Economy	Day	Night	Economy
Constant	69.8790	−79.5895	26.7234	141.454	1.6297	3.0418
	(65.4319)	(96.2353)	(41.2924)	(118.143)	(34.0951)	(25.5964)
D10						
N10						
D30						
N30						
D100						
N100						
E100						
D800	−0.53861	0.42087	−0.06410			
	(0.93545)	(1.37167)	(0.58922)			
N800	0.59701	−0.61420	0.58003			
	(1.68625)	(2.47171)	(1.06530)			
E800	−0.10019	0.87536	0.23352			
	(1.35602)	(1.99146)	(0.85820)			
D801				−0.31240	−0.19337	−0.01937
			(0.80994)	(0.33004)	(0.24819)	
N801				−1.17380	−0.29461	−0.17950
			(1.03180)	(0.31633)	(0.23582)	
E801				−0.32105	(−0.24315)	−0.41162
			(1.18801)	(0.48123)	(0.36214)	
INCOME	0.00145	0.00670	−0.00081	0.00061	0.00176	−0.00099
	(0.00122)	(0.00181)	(0.00077)	(0.00234)	(0.00053)	(0.00040)

HOMEOWN	−45.6398	46.6969	5.0022	0.52564	6.03944	2.68941
	(22.0714)	(32.5776)	(13.9258)	(42.1490)	(9.54262)	(7.21940)
MOVERS	−15.6717	308.749	23.5837	−17.6357	1.23246	9.98726
	(27.2699)	(40.2518)	(17.2059)	(52.0849)	(11.7832)	(8.91483)
UNEMPLOY	−26.4230	−32.7497	−34.3309	−0.78876	5.40860	−15.3123
	(33.4373)	(49.3530)	(21.0969)	(63.7193)	(14.4365)	(10.9216)
HHSIZE	−6.54186	−23.3763	−5.61851	−19.2041	−21.6170	1.20011
	(11.5641)	(17.0694)	(7.29629)	(22.1110)	(5.00147)	(3.78403)
SINGLE	−38.9134	91.9561	−7.34322	−57.6298	−5.32212	3.43442
	(20.9501)	(30.9233)	(13.2183)	(39.9907)	(9.04177)	(6.84090)
AGE014	1.40488	36.9007	12.1802	0.59222	20.3296	3.08656
	(11.9261)	(17.6037)	(7.52469)	(22.7979)	(5.15758)	(3.90214)
AGE1524	−6.86164	9.29661	5.77545	−17.7150	32.2995	5.80545
	(12.7727)	(18.8531)	(8.05890)	(24.3946)	(5.51399)	(4.17183)
HEADU25	−22.6779	−57.2041	−42.9383	8.13230	−36.6208	2.46924
	(38.1759)	(56.3468)	(24.0868)	(72.7087)	(16.4479)	(12.4441)
HEAD2534	−3.96970	67.8663	−16.0730	−3.76333	17.1664	6.24748
	(27.6943)	(40.8779)	(17.4736)	(52.9335)	(11.9827)	(9.06527)
HEAD3544	28.5625	40.1723	−17.1985	20.5480	6.99981	−4.01359
	(25.4683)	(37.5922)	(16.0691)	(48.6624)	(11.0143)	(8.33279)
HEAD4554	19.9444	61.6077	−17.9513	99.5780	31.2376	−0.27614
	(24.9183)	(36.7802)	(15.7220)	(47.6370)	(10.7861)	(8.15988)
HEAD5564	49.5196	57.3304	3.04139	−10.4590	4.62505	−11.0952
	(25.0725)	(37.0064)	(15.8195)	(47.8331)	(10.8362)	(8.19745)
Correction	0.39556	−0.19266	−0.82295	−1.12591	0.34559	1.03504
	(2.23589)	(3.30013)	(1.41073)	(4.27133)	(0.96954)	(0.73341)

Note: Standard errors in parentheses.

current Telecom Australia charges. It is interesting to note that the highest estimated own-price elasticities occur for the longest distance band, with demand having a slightly higher than unitary elasticity for economy calling in this distance band. Removal of regulation would apparently provide the least incentive for price increases for calling over the longest distances.

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