Optimal Fixed-to-Mobile Interconnection Charges

Paper presented at the 12th European Regional ITS conference Dublin, 2-3 September 2001

Christian Koboldt and Dan Maldoom*

Keywords: Ramsey prices, mobile telephony, call termination, fixed-to-mobile calls

JEL classification: C15, D59, L51, L59

Abstract

Determining a socially optimal tariff structure for mobile telephony is largely a question about how costs that are fixed or common across services should be efficiently recovered. Charging for service elements at long-run incremental costs would not be sustainable, as this would lead operators to making substantial losses. Prices of services should include some mark-ups to recover the common part of costs, possibly in an efficient manner.

Whilst the efficiency properties of Ramsey prices are generally acknowledged, regulatory authorities usually prefer a system of equi-proportionate mark-ups (EPMUs) because of its simplicity and relative ease of implementation. For example, Oftel, the telecoms regulatory body in the UK, has expressed a preference for using the EPMU method in determining the level of mobile call termination charges should it find regulatory intervention to be required.

Choosing the relatively simple system of EPMUs in place of a Ramsey approach may be acceptable where the underlying demand conditions are such that Ramsey prices are not too different from EPMU prices. However, in this paper we demonstrate that for a wide variety of elasticity estimates, the divergence between socially optimal Ramsey prices and prices that would result from the application of EPMU is significant.

Modelling the mobile market as a single sector offering three distinct services – subscriptions, call origination and call termination – we calibrate a model of optimal Ramsey prices for mobile services and fixed-to-mobile calls using UK market data. In order to deal with the problem of potentially distorted elasticity estimates because of limited data availability, we use a bootstrap approach to produce a range of estimates. Using these estimates to calibrate our demand system, we numerically solve for the corresponding Ramsey prices. Over the entire range of parameter estimates we find that the socially optimal mark-up on fixed-to-mobile calls is considerably higher than the corresponding EPMU. This suggests that using EPMU instead of Ramsey prices in the regulation of mobile charges is likely to result in considerable welfare losses.

---

* DotEcon Ltd, 105-106 New Bond Street, London W1S 1DN, phone +44-20-7870 3800, fax +44-20-7870 3811, email christian.koboldt@dotecon.com / dan.maldoom@dotecon.com. This work is based on research undertaken for BT Cellnet, and we are grateful to our colleagues Roger Salsas, Carlo Savino and Mathew Stalker for support in preparing this paper. The usual disclaimer applies.

1. INTRODUCTION

Several telecommunications regulatory and competition policy bodies have recently considered whether charges for calling mobile phones are excessive.[1] It has been argued that for structural reasons competition in the provision of call termination services may be ineffective, allowing mobile network operators (MNOs) to charge excessively for the termination of calls destined for their subscribers. According to this argument, even if competition between MNOs for subscribers were effective, this may not lead to sufficient competitive pressure on call termination services because it is the calling party, not the called customer for whom MNOs compete, who pays for the call. Those who pay for call termination are not the same as those who chose the network that will ultimately have to provide the call termination service.

Whilst this problem would disappear if the called party were concerned about the cost of being called (for example because the cost is effectively borne by the same economic entity – a business or a family or where regular reciprocal calling may establish a effective common economic interest) or if call-back imposed a constraint on the extent to which the cost of calling from a mobile and calling the mobile subscriber can diverge, in practice these effects have not been considered to be sufficiently strong to act as an effective check on the power of MNOs to set call termination charges at excessive levels.[2] Customer ignorance about the cost of calling mobiles and, perhaps more importantly, about the specific network to which a particular subscriber is connected[3] further reduces the extent to which competition can be effective in the provision of call termination services. The extent to which call termination charges exceed the cost of providing call termination services (usually measured as the long-run incremental cost of terminating calls on a particular network) is generally regarded by regulatory authorities as strong evidence that whatever competitive pressure might exist in the mobile market does not extend to call termination.

However, it would be spurious to conclude that the calling party pays principle (CPP) leads to market power in mobile call termination. Even if call termination rates were above social optimal levels, competition for subscribers still has the potential to dissipate supernormal profits. Therefore, CPP cannot be regarded as leading to market power in any traditional sense. Rather, CPP gives rise to an externality (i.e. a situation where the

[1] See, for example, the recent consultation documents issued by the ACCC /1/ and Oftel /16/.

[2] For an overview of the arguments see the report prepared by the UK Monopolies and Mergers Commission /15/.

[3] In this regard, the introduction of mobile number portability creates an additional problem as it makes it even more difficult to establish a clear link between a mobile subscriber's number and the network to which this subscriber is connected.

choice of one party – the mobile subscriber's choice of network – impacts upon the costs that have to be borne by a another party – the fixed line customer ringing the mobile). Such externalities are ubiquitous in communications markets, and without further evidence should not be regarded as a fundamental problem requiring regulatory intervention.

Competition between mobile operators has to be assessed in terms of bundles of services rather than specific elements such as call termination. Call termination cannot be provided in isolation, but always requires that there is a customer (subscriber) relationship between the party on whose mobile phone a call is terminated, and the operator providing call termination. Because call termination will always be provided as part of a service bundle, there is no reason why call termination charges should equal LRIC even in a hypothetical world where competitive constraints such as call-back were effective. Rather, call termination charges would include a mark-up to recover fixed and common costs incurred in the provision of the bundle, and it is socially optimal for callers to bear some of this cost.

The theoretically optimal benchmark – for both identifying the need for regulatory intervention and implementing regulatory policy – is a set of Ramsey prices for various mobile services, which minimise the welfare loss associated with recovering fixed and common costs through mark-ups on marginal costs. Although regulators generally acknowledged that Ramsey prices are the correct theoretical benchmark, in practice there is a strong preference for using schemes such as equi-proportionate mark-ups (EPMUs) on LRIC for reasons of simplicity. This may well be justified where the welfare loss from using EPMUs instead of Ramsey prices is relatively small. However, as we argue in this paper, there are good reasons to believe that this is not the case with regard to fast growing markets such as mobile telephony.[4] Regardless of the specific values of price elasticities, the impact of pricing on the growth of mobile penetration is likely to result in superelasticities that are unequal across service elements and imply considerable optimal mark-ups on call termination.

Throughout this paper, we abstract from the specific competitive interaction between mobile operators and treat the mobile sector as a single entity. As we are concerned with first best optimal prices (subject to the usual inability to make transfers), this is an appropriate approach. We should, however, note that there is a considerable body of literature focusing on the relationship between pricing of interconnection services and the nature of competition (see, for example, Laffont, Rey and Tirole /12,13/, or Armstrong /3/; with specific focus on the mobile sector see Wright /18/ or Gans and King /8/), and incorporating models of competitive interaction between mobile operators clearly is an attractive option for future research. However, we do not

[4] Calibrating our model to UK data suggests a welfare loss in the order of £300million per annum from using EPMU pricing rather than Ramsey pricing.

consider a second-best world in which oligopolistic competition for mobile customers may be affected by call termination rates. In effect, we are considering optimal regulation if competition for mobile customers is effective.

This paper is organised as follows. In Section 2 we discuss the efficient call termination benchmark from a theoretical perspective. Section 3 provides a brief overview of the Ramsey approach and sets out our model structure. In Section 4 we describe how we estimated the relevant demand parameters. Section 5 presents our main results, and Section 6 draws conclusions and indicates directions for future research.

2. THE EFFICIENT CALL TERMINATION BENCHMARK

Across the board, when faced with problems of fixed or common cost recovery, Oftel has indicated a preference for EPMU, in which different service elements are marked up in the same proportion. In contrast, Ramsey pricing seeks to structure these mark-ups in order to minimise the distorting effect of pricing services above marginal cost. Although Ramsey pricing has strong theoretical justifications, it does require relatively detailed information about demand conditions and, in particular, price elasticities. For this reason, Oftel has favoured EPMU because of its simplicity and practicability.

In some situations, EPMU may indeed be a tolerable approximation for Ramsey pricing if the superelasticities of different services are similar. However, the particular circumstances of mobile telephony mean that EPMU and Ramsey prices are likely to be very different, with significant welfare loses associated with using EPMU. Any measures that lead to higher mark-ups on services that affect consumers' decisions whether or not to become or continue being a mobile phone user (in particular, subscription charges for post-paid customers and mobile call charges for all customers) will have knock-on effects on other strongly complementary services. The structure of optimal mark-ups should reflect this.

2.1. COMPETITION, LRIC AND COMMON COST RECOVERY

In its consultation paper on calls to mobile phones, Oftel /17/ states that LRIC should form the basis for determining economically efficient charges:

> *whenever regulatory control of charges is required to protect consumers from excessive charging by operators with market power, the most appropriate and economically efficient basis for the charges is long run incremental costs (LRIC). Forward- looking costs are based on a current, rather than an historic, valuation of assets.* (paragraph 1.13)

This is based on Oftel's belief that:

> *charges set on this basis most accurately reflect the resources consumed by the provision of services and correspond most closely to the level which would occur in a fully competitive market. (ibid.)*

This belief that economic efficiency is furthered by LRIC-based prices appears to mirror the standard economic textbook result that in a perfectly competitive market, where all economic rents are competed away, prices are determined by long-run incremental costs (in essence, average variable costs).

The theoretical notion of the 'long run' time period in which all costs are ultimately variable is clearly of limited practical relevance. Over any realistic planning horizon, many costs will be fixed and possibly common across more than one service, leading to significant economies of scale and scope. In the case of telecommunications, a considerable proportion of the costs incurred by an operator is common across the individual services provided.

Under such circumstances, pricing individual services on the basis of LRIC will, in general, not lead to recovery of total costs and so cannot be a realistic outcome of effective competition, as Oftel acknowledges. Using LRIC as a competitive benchmark implicitly assumes that the service in question could in principle be provided on a stand-alone basis without the loss of economies of scale and scope, which is obviously inappropriate.

This implies that the prices set by competition in the supply of services which are provided subject to economies of scale and scope will contain a mark-up over marginal cost (or incremental cost). Firms competing with each other would have a strong incentive to try to recover such common costs in a manner that is best for consumers. This would mean loading fixed and common costs onto those services where they can increase prices most easily without losing demand, i.e. on those services for which demand is least elastic.[5]

Thus, an appropriate 'competitive benchmark' should allow for efficient recovery of fixed and common costs, which in turn depends on demand conditions. The necessity of considering not just cost conditions, but also demand conditions, in determining optimal pricing in the telecoms sector has been emphasised by many authors (for many examples see Laffont and Tirole /11/).

2.2. MARK-UP METHODOLOGIES

Regulation has acknowledged the need for marking up LRIC, and Oftel has discussed a number of alternative mark-up methodologies in a paper presented to the LRIC working group, including Ramsey pricing and equi-proportionate mark-ups (EPMUs). The Ramsey approach to some extent mirrors the pricing decision faced by individual operators in a competitive market in that it recommends loading fixed and common

[5] We should note that 'elastic' in this context refers to superelasticities, which include own-price as well as cross-price effects, rather than simple own-price elasticities of demand. For a more detailed discussion of superelasticities see Section 3 below.

costs on those services for which demand is least elastic, with the difference that in a planning approach the relevant elasticities would be based on the market demand rather than the firm-specific demand.

Oftel /16/ rejects the Ramsey approach because of the practical problems with its implementation, whilst *"the equi-proportionate mark-up has the advantage of being easy to implement and so would reflect the principle of practicality*." Put succinctly, this amounts to the view that it is better to be 'precisely wrong' than to be 'approximately right'.

In some particular cases, the structure of consumers' demands for services may indeed mean that EPMU is a tolerable approximation to Ramsey pricing. In particular, where:

- elasticities for different services are reasonably similar; and
- the services in question are all either substitutes or complements to each other to a generally similar degree,

These conditions are sufficient to imply that different services have similar superelasticities and so similar Ramsey prices. However, if one or both of these assumptions fail to hold, EPMU will not yield close to optimal results.

In the case of mobile pricing, there are strong reasons to believe that the EPMU approach and Ramsey pricing will give very different answers as the structure of demand is such that the two assumptions above do not hold. Therefore, applying EPMU on the grounds of it being simpler than Ramsey pricing could lead to significant welfare losses. In this case even approximate Ramsey prices based on best guesses of demand conditions may be preferable to using EPMU.

2.3. THE MOBILE SERVICE BASKET

Mobile operators compete with each other to win new customers – both those taking out a mobile subscription or buying a prepaid package for the first time and those switching between operators – and retain their existing ones. They attract customers by offering a selection of tariff packages, combining various tariff components (handset price, connection fee and monthly subscription charges for post-paid customers, charges for making calls and using value-added services such as SMS, voice mail retrieval or various information services). Customers choose the most appropriate tariff package, given their preferences and their anticipated mobile usage. Operators need to price individual service elements within these packages in a manner that is attractive to customers in order to recover common and fixed costs.

In attracting customers, mobile operators compete for the many different revenue streams these customers generate, including:

- connection/subscription revenues;
- revenues from mobile-originated calls;
- revenues from the provision of value-added services such as SMS or information services; and

- call termination revenues.

Competition for subscribers should ensure that the total revenues earned from customers do not exceed the total costs of serving them, including customer acquisition costs and a competitive rate of return on assets.

This does not imply that revenues from each particular service will exactly cover the identifiable costs incurred in the provision of this service. Perhaps the most obvious example is the pricing of handsets. In order to reduce the upfront cost a customer would otherwise have to incur when purchasing a mobile (subscription or pre-paid), MNOs offer considerable handset subsidies. This encourages customers to try out mobile services without being exposed to the risk of making a potentially significant investment in hardware only to find out that they have over-estimated the benefits from using mobile telephony services. As handsets are priced below cost, this obviously implies that connection revenues, which include the price the customer pays for handsets, do not cover the costs incurred by the mobile operator. However, there are good reasons why MNOs engage in this pricing strategy, and this practice is common in markets where customers need hardware in order to be able to use services and would otherwise bear a large risk of experimenting with new services - heavily subsidised satellite dishes and receivers or discounted game consoles are some examples.

More generally, mobile operators have an incentive to take into account the extent to which customers are responsive to price changes. For example, if increasing the subscription charge would discourage take-up, but increasing call charges does not, then the MNO has an incentive to reduce subscription charges and increase call charges, perhaps even to the extent that subscription charges do not cover the long run incremental cost per subscriber. The fact that charges for some services are – perhaps significantly - above LRIC may not indicate a lack of competition, but rather the fact that customers are less price sensitive with regard to those services. Effective competition should, nevertheless, lead to overall cost recovery across a basket of services, as other more price-sensitive services will bear a lower share of common cost.

2.4. THE RELEVANT BENCHMARK

By itself, LRIC does not provide a competitive benchmark for call termination as it is not a service which could be supplied competitively without at the same time supplying the other elements of the mobile bundle. The issue of common cost cannot be ignored and is likely to have a much greater impact on the optimal level of tariffs than will the precise estimation of LRIC. Therefore, Oftel's emphasis on LRIC as the basis for determining a competitive benchmark is somewhat misplaced given that applying mark-ups to LRIC is far from being a small 'correction' but rather central to the ultimate conclusions reached. The socially optimal benchmark, should be determined within a Ramsey pricing framework, taking account of:

- the efficient recovery of fixed and common costs across all elements of the service bundle; and
- the presence of network externalities, which arise from the fact that calling parties (including fixed-to-mobile callers) benefit from an

increase in the number of mobile subscribers, but that this benefit is not being taken into account in the decision whether to purchase a mobile subscription or a prepaid package.

Whilst there may be situations in telecoms regulation in which EPMU is approximately correct, there are strong reasons to believe that in this particular case of mobile pricing, Ramsey prices are far from those set by EPMU due to the structure of the mobile service basket. We demonstrate this below by estimating Ramsey prices using a model calibrated on the basis of market data. However, the point is a very general one:

Where there are complementarities between individual services in the bundle offered by mobile operators, the recovery of fixed costs should take account of not just the direct impact of reducing the demand for a particular service on demand for that service, but also on demand for other related services. Formally, optimal mark-ups depend on superelasticities that reflect the impact of changing the price of one service on all services. Unlike the fixed market, the mobile market is partially penetrated and still growing. Clearly take-up decisions are strongly complementary with call volumes, as without a handset it is not possible to make or receive calls. Particular aspects of the mobile pricing bundle are important in affecting take-up and the mark-up they receive to recover common costs efficiently should reflect this.

3. THE RAMSEY MODEL

3.1. THE GENERAL FRAMEWORK

We first illustrate these general points in a simple two-good Ramsey pricing model. Assume, for simplicity, that common fixed costs F are incurred in the production of two goods, 1 and 2. Production of additional units of the two goods incurs marginal costs of c_1 and c_2 respectively. Suppose that demand is given by functions $d_1(p_1, p_2)$ and $d_2(p_1, p_2)$. Here the pricing of one good can affect the demand for the other, so we allow for the possibility of substitutes or complements.

The Ramsey problem of optimising social welfare can be written as

$$\max_{p_1, p_2} W(p_1, p_2)$$
$$s.t. (p_1 - c_1)d_1(p_1, p_2) + (p_2 - c_2)d_2(p_1, p_2) \geq F$$

with $W(p_1, p_2)$ is the gross surplus enjoyed by consumers if they face prices p_1 and p_2 for the two goods.[6]

The first order conditions of the corresponding Lagrange problem are given by:

$$\frac{1-\lambda}{\lambda} d_1 = m_1 \frac{\partial d_1}{\partial p_1} + m_2 \frac{\partial d_2}{\partial p_1}$$
$$\frac{1-\lambda}{\lambda} d_2 = m_1 \frac{\partial d_1}{\partial p_2} + m_2 \frac{\partial d_2}{\partial p_2}$$
$$m_1 d_1 + m_2 d_2 = F$$

where $m_i = (p_i - c_i)$ is the absolute mark-up on marginal costs for each product and λ is the Lagrange multiplier. Collecting and re-arranging terms, we obtain the following condition for the relative Lerner indices $L_i = \frac{p_i - c_i}{p_i}$ on the two products:

$$\frac{L_1}{L_2} = \frac{\varepsilon_{11} - \frac{p_2 d_2}{p_1 d_1}\varepsilon_{21}}{\varepsilon_{22} - \frac{p_1 d_1}{p_2 d_2}\varepsilon_{12}}$$

where ε_{ii} denotes the own-price elasticity of demand for good i and ε_{ij} stands for the cross-price elasticity.

This condition has the following implications:

- If the two goods are neither substitutes nor complements (i.e. cross-price elasticities are zero), the good with the more elastic demand should have a smaller mark-up. This is because increasing the price of the more elastic good leads to a greater welfare loss than increasing the price of the less elastic one.

- If one good is a complement to the other good, it should have a smaller mark-up than would otherwise be the case. Increasing the price of such a good reduces not just the consumption of that good, but also the

[6] Here the gross surplus function is the optimised value of consumers' utility at prevailing prices. It can be shown that $\frac{\partial W}{\partial p_i} \equiv d_i$.

demand for complementary goods, reducing the contribution that they make to recovering fixed costs.

- Conversely, if one good is a substitute for the other good, it should have a larger mark-up that would otherwise be the case. Increasing the price of this good increases the contribution to fixed cost recovery made by other goods.

Further, it may well be optimal for mark-ups to be negative, i.e. for some goods to be sold below marginal costs. This can be the case where products are strong complements, i.e. where an increase in the price of one product not only reduces demand for this product, but also for the other product. In this particular case, it may well be optimal to subsidise a product if its own revenue contribution is sufficiently small (i.e. the majority of revenues are earned from providing the complementary product) and the cross-price effects leading to greater revenue contributions from other products are sufficiently strong. This is relevant in the case of mobile phones where the impact of handset subsidies may be considerable in that demand for mobile calls and demand for fixed-to-mobile calls, and the social benefits from satisfying this demand, tend to grow in line with the number of mobile subscribers.

3.2. OUR MODEL

We consider Ramsey prices for a stylised model of three interlinked mobile services: mobile subscriptions (including pre-paid and post-paid customers), mobile-originated calls and call termination.

In our specific case, we simplify our demand system by assuming that:

- the demand for mobile telephones d_S (the take-up of subscriptions and pre-paid packages) depends on the price of subscriptions p_S (including the connection fee/handset cost spread over the lifetime of a customer) and the price of calls p_C (we do not distinguish different types of calls made at different times), i.e. $d_S = d_S(p_S, p_C)$

- the demand for mobile calls d_C depends on the price of calls p_C and the number of mobile subscribers, which in turn depends on the price of mobile calls and mobile subscriptions, i.e. $d_C = \tilde{d}_c\left(p_C, d_S(p_S, p_C)\right) = d_C(p_S, p_C)$

- the demand for fixed-to-mobile calls d_F depends on the price of fixed-to-mobile calls p_F and the number of mobile subscribers, which in turn depends on the price of mobile calls and mobile subscriptions, i.e. $d_F = \tilde{d}_F\left(p_F, d_S(p_S, p_C)\right) = d_F(p_S, p_C, p_F)$

The corresponding first order conditions of the welfare maximisation problem are:

$$\frac{1-\lambda}{\lambda}d_S = m_S\frac{\partial d_S}{\partial p_S} + m_C\frac{\partial d_C}{\partial p_S} + m_F\frac{\partial d_F}{\partial p_S}$$
$$\frac{1-\lambda}{\lambda}d_C = m_S\frac{\partial d_S}{\partial p_C} + m_C\frac{\partial d_C}{\partial p_C} + m_F\frac{\partial d_F}{\partial p_C}$$
$$\frac{1-\lambda}{\lambda}d_F = m_F\frac{\partial d_F}{\partial p_F}$$
$$m_S d_S + m_C d_C + m_F d_F = F$$

The overall approach we have taken is to:

- specify reasonable functional forms for the demand functions d_c and d_f, and subscription take-up d_s in terms of a small number of parameters;.
- calibrate these parameters and obtain the system of equation that identifies the cross- and own-price elasticities;
- compute the solution to the Ramsey pricing problem by jointly solving the system of first order conditions using numerical methods.

4. DEMAND ESTIMATION

In this section we discuss the models used for estimating demand parameters to calibrate the model.

4.1. FIXED-TO-MOBILE CALLS

We have estimated the elasticity of fixed-to-mobile calls using data on total retail call minutes to mobile phones from BT fixed lines split by day, evening and weekend for each operator; day, evening and weekend retail tariffs for calls to each operator; the total number of handsets for each mobile operator and real household income on a monthly basis over a period of more than two years. Full details of our approach can be found in DotEcon /7/, and the results are summarised in Table 1.

Table 1: Fixed-to-mobile call elasticities

	Revenue weight	*Price elasticity*	*Mobile subscriber number elasticity*
Daytime	71.7%	-0.33	0.50
Evening	21.6%	-0.76	0.78
Weekend	6.8%	-0.43	0.75
Weighted average		**-0.43**	**0.58**

Source: DotEcon /7/

Our price elasticity estimate is in line with an estimate reported in Aldebert et al. /2/… for the French market.

4.2. MOBILE-ORIGINATED CALLS

Our approach to modelling the demand for mobile originated calls and subscriptions is loosely based on common differentiated consumer models of telecoms demand. In particular, suppose that consumers are drawn from a single-parameter distribution of types. Demand for calls depends on call price and the customer's type. If we suppose that the type parameter affects call demand multiplicatively, we can aggregate across types. If $a(\theta)d_c(p_c)$ is the call demand from a customer of type θ, then aggregate demand for calls is given by $A(\theta^*)d_c(p_c)$ where

$$A(\theta^*) = N\int_{\theta^*}^{\bar{\theta}} a(\theta)\,dF(\theta).$$

Here θ^* is the lowest type of customer currently subscribing, $\bar{\theta}$ is the highest type, $F(\bullet)$ is the distribution of types and N is the total number of customers. If a is an increasing function, those consumers who are first to subscribe are the heaviest users and so we can interpret θ^* as a measure of penetration. We can write aggregate demand for calls as a function of call prices and subscribers numbers (or penetration). This can be log-linearised to give a relationship amenable to estimation.

However, there are a number of practical difficulties in performing such an estimation:

- First, operators use complex menus of tariffs, so different customers will face different marginal prices for calls. At best, we can hope to observe an average of marginal call prices across customers.
- Second, publicly available data for the United Kingdom (from Oftel Market Information) does not distinguish between revenues from calls

and from subscriptions. We cannot directly observe marginal call prices at all.

Using average revenue per call minute – which can be calculated very easily on the basis of Oftel data as a proxy for the price of calls has the problem that it includes subscription charges. Any model based on average revenue per call is open to the criticism that there would be a negative relationship between average revenues per call minute even if call prices remained unchanged simply because subscription charges being spread across greater call volumes would lead to a fall in average revenues per call. The failure to take this issue into account could bias the estimation of own price elasticity, leading to an elasticity that is too large in magnitude. However, the information that would be required to net off subscription revenues and calculate average call prices is unavailable, and we cannot correct for any bias that might result from using average revenues per subscriber as a proxy for call prices.

We consider each individual operator's call minutes as a function of the average revenue per call for that operator (a proxy for that operator's average call price) and the average revenue per call across other operators (a proxy for an average of competitors' average call prices). This allows us to identify both firm-specific and market elasticities.

For each operator, we compute an *alternative price per call minute* ($ALTP_{it}$), available from other operators by taking the average of P_{it} (the average revenue per call minute) across competing mobile operators $j \neq i$. We estimate the following model:

$$\ln(CALLMIN_{ti}) = \alpha + \beta_1 \ln(P_{ti}) + \beta_2 \ln(ALTP_{ti}) + \\ \beta_3 \ln(SUBSCRIBERS_{ti}) + \beta_4 \ln(Y_t) + v_i + e_{ti}$$

using a fixed effects regression that allows for unobserved characteristics in the demand of each operator (v_i). The results are reported in Table 2.

Overall, we find that this disaggregated model gives much more credible results than aggregated models. The call demand faced by an individual operator is significantly negatively related to its own 'call price' as proxied by average revenue per call, and significantly positively related to competitors' average prices. Call volumes increase as the number of subscribers increases, but less than proportionately.

An overall market elasticity can be found by supposing that all operators' prices increase at the same time, so that $\beta"_1 + \beta"_2$ is the implied market elasticity.

Table 2: Disaggregated long-run model for mobile originated minutes

	Coefficient	*t-stat*	*p-value*
ln(P)	-0.794	-17.38	0.000
ln(ALTP)	0.405	3.86	0.000
ln(SUBSCRIBERS)	0.770	17.81	0.000
ln(Y)	1.964	2.29	0.025
Constant	-14.679	-1.50	0.138
R^2 Overall	0.924		
Joint significance of regressors: F(4, 68)	2112.45	Pr	0.000
Joint significance of fixed effects: F(3, 68)	33.74	Pr	0.000
Observations	76		
Groups	4		

In addition to the model presented above we also estimated a random effects model. However, as there was little cross sectional variation, this method largely reduces to OLS. Further, we estimated the above model using the lagged values of price and alternative price as instruments for price and alternative price. A Hausman test for exogeneity of regressors is passed, so we use OLS estimates rather than IV estimates.[7]

We have also estimated a corresponding short-run error correction model for changes in call volumes:

$$\Delta \ln(CALLMIN_{ti}) = \alpha' + \beta_1' \Delta \ln(P_{ti}) + \beta_2' \Delta \ln(ALTP_{ti}) +$$
$$\Delta\beta_3' \ln(SUBSCRIBERS_{ti}) + \beta_4' \Delta \ln(Y_t) + \beta_5' e_{(t-1)\,i} + v_i' + e_{ti}'$$

We find significant relationships of appropriate sign between call volumes, own and competitor prices and number of subscribers. In addition, we find a significant negative co-efficient on the error-correction variable. This can be interpreted as evidence that the volumes converge in the long run to those given in the levels model reported in Table 2.

[7] Here we are limited in the number of lags of prices that can be used as instruments due to having few observations.

Therefore, although call volumes and prices are trended, there appears to be a robust long-run relationship given by the levels model.

The operator-specific model reported in Table 2 is similar to that presented in Dineen /5/, who also attempted to estimate mobile-originated call volume elasticities using the OMI data. Dineen takes a similar approach and regresses call volumes on total revenues from subscriptions and calls averaged over call minutes. However, there are some significant differences between the Dineen model and this one:

- the time periods are slightly different;
- Dineen does not separate own- and cross-price effects, and estimates an elasticity of around –0.4, which has to be interpreted as an amalgam of firm-specific and market elasticities;

Interpreting the Dineen elasticity as an amalgam of firm-specific and market elasticities, we find that the results are broadly consistent with ours, but that they are not easily interpretable for the purposes of estimating a market elasticity.

4.3. MOBILE SUBSCRIPTIONS

Based on our model of consumer choice, we can determine the marginal participating type $\theta *$ from an indifference condition

$$a(\theta *)v(p_c) - p_c a(\theta *) d_c(p_c) - p_s = 0$$

where $a(\theta)v(p_c)$ is the gross consumer surplus of a consumer of type θ. This relationship is potentially complex as $\theta *$ will depend on both p_s and p_c, but it defines a relationship between penetration and the cost of using mobile telephony. In particular, we can write this relationship as $h(\theta *, p_c) =$ average mobile bill for some function *h*.

This model of penetration depending on the prices is related to standard models of technology adoption that capture the change in the proportion of the population using a particular technology over time.[8] These models suggest reasonable functional forms for *h*.

Penetration (the proportion of final subscribers that have adopted mobile telephony) tends to follow three stages:

- an initial period of low penetration with take-up increasing slowly;

[8] For an overview see Mahajan et al /14/.

- followed by a period of penetration increasing rapidly; and
- finally a period in which penetration increases more slowly as the market approaches saturation.

The most flexible function for capturing this adoption process is the Gompertz curve,[9] which has the double logarithmic form:

$$\ln\left(\ln Population \ -\ln Subscribers_t\right) = \ln(k) - qt$$

where *k* and *q* are parameters defining the speed of adoption.

Allowing the speed of take-up to depend on the cost of using mobile telephony[10] we have estimated the following functional form for the Gompertz curve:

$$\ln\left(\ln Population \ -\ln Subscribers_t\right) = \alpha + \beta \ln(Bill_t) + \gamma t + e_t$$
$$\ln(Bill_t) = \gamma + \ln(Bill_{t-1}) + \varepsilon_t$$

using lagged bill as the instrumental variable.[11] Although theory would suggest also including call prices they are difficult to measure and any available estimates on the basis of publicly available data are strongly correlated with average bills.

Our results are presented Table 3, which shows a positive and significant coefficient on the size of the bill. This indicates that an increase in price will result in people delaying their decision to subscribe to the mobile network, as one would expect. Furthermore, the coefficient on time is negative and significant indicating that penetration increases over time.

In order to verify that this result is not driven by trended data we estimated the corresponding short run model, of the form:

$$\Delta \ln\left(\ln\left(Population_t\right) - \ln\left(Subscribers_t\right)\right) = \alpha' + \beta' \Delta \ln\left(BILL_t\right) + \varepsilon_t .$$

Again, the coefficient on bill is positive and significant, though smaller owing to penetration changing more slowly in the short run. Furthermore, the coefficient on the

---

[9] The Gompertz curve is a very flexible way of capturing asymmetric diffusion processes (see Hendry /9/ or Dixon /6/).

[10] For a more general discussion see Bass /4/ or Jain and Rao /10/.

[11] It is difficult to obtain data to construct satisfactory instrumental variables. A superior approach might be to use mobile prices in other EU countries as the instruments.

constant is negative and significant, indicating that penetration does indeed increase over time.

Table 3: Long run Gompertz Model of Subscription

	Coefficient	*t-stat*	*p-value*
ln(BILL)	2.377	6.09	0.000
Time	0.0426	2.25	0.040
Constant	-10.248	-5.48	0.000
R^2	0.952		
Joint Significance of regressors: F(2, 15)	194.59	Pr	0.000
Hausman specification test against OLS regression: $Chi^2(2)$	24.54	Pr	0.000
Observations	18		

5. CALCULATION OF RAMSEY PRICES

5.1. APPROACH

Our overall approach is to calibrate our demand system using these econometric estimates. However, owing to the small number of observations available over time, these estimates may not be entirely satisfactory. Given small sample problems, parameters may be less well determined than their standard errors suggest. Furthermore, our model of mobile adoption may not be particularly well specified, but exploration of richer alternatives may not be feasible on the basis of available aggregate public domain data. For these reasons, we have adopted a bootstrapping approach and considered a wide range of parameter estimates when comparing Ramsey and EPMU prices.

We first generate an empirical distribution of parameter estimates by bootstrapping our original data. We then calculate Ramsey prices for the set of coefficients from the estimation for each bootstrap repetition by:

- using these coefficients together with actual price and quantity data in order to calibrate intercepts of the demand system; and
- solving numerically for the optimal set of prices.

Using a sufficiently large number of bootstrap repetitions (50,000) allows us to identify the distribution properties of the associated Ramsey prices and mark-ups. The summary statistics for the key demand parameters are presented in Table 4.

Table 4: Summary statistics for bootstrap parameters

Coefficient	*Mean*	*Median*	*StdDev*	*90% Confidence Interval*	
Mobile originated calls					
ln(P)+Ln(ALTP)	-0.411	-0.400	0.150	-0.178	-0.668
ln(SUBSCRIBERS)	0.765	0.768	0.059	0.859	0.668
Mobile subscriptions					
ln(BILL)	2.532	2.412	0.744	3.683	1.740
Fixed-to-mobile calls					
Price elasticity	-0.407	-0.409	0.141	-0.170	-0.637
Mobile subscriber number elasticity	0.586	0.583	0.057	0.684	0.497

5.2. CALIBRATION PRICES AND QUANTITIES AND COST DATA

To calibrate our demand system, we used price sensitivity and call volume to subscriber sensitivity parameters from the equations reported above. However, we determine the intercepts of the demand equations by requiring that the demand system pass through a price-quantity combination that represents actual market outcomes in the second quarter of 2000/2001.

5.2.1. FIXED-TO-MOBILE CALL PRICES

In order to capture the existence of various discounts and differences in prices across operators, we use the average revenue per fixed-to-mobile call as a proxy for fixed-to-mobile call prices. Total revenue and volume figures have been taken from Oftel Market Information (see Table 5) below. Throughout, we will distinguish between the retail price of fixed-to-mobile calls and the wholesale price (i.e. the termination charge) which is equal to the retail price less the fixed operators costs and margin (the so-called 'retention').

Table 5: Average fixed-to-mobile call price

Revenues from fixed-to-mobile calls (£million/quarter)	438
Fixed-to-mobile call volumes (million minutes/quarter)	3,105
Average fixed-to-mobile call price (pence per minute)	14.10

Source: Oftel Market Information, Quarter 2 2000/01

5.2.2. MOBILE CHARGES

Oftel Market Information does provide total mobile revenues, subscriber numbers (split into pre- and post-pay) and call minutes, but does not provide a breakdown of subscription and call revenues. In order to split total mobile revenue into subscription revenues and call revenues, we have assumed an average post-pay subscription of £17.50 per month, and weighted this with the share of post-pay subscribers as a proportion of the total mobile subscriber base. Subtracting the implied subscription revenues from the total revenue figure provided by Oftel, and dividing the remainder by the total number of call minutes, implies an average charge for mobile originated call minutes. Table 6 summarises our assumptions about calibration prices and quantities.

Table 6: Prices and quantities used for calibration of demand models

	Price	*Quantity*
Fixed-to-mobile calls	14.10 ppm (Total revenues from fixed-to-mobile calls divided by total volume)	3.105 billion mins/qtr
Subscriptions	£19.55/quarter (assumed average monthly subscription of £17.50 for post-paid packages multiplied by the share of post-paid customers)	34,380,000
Mobile-originated calls	12.82 ppm (total revenues from call and fixed charges less imputed subscription revenues divided by total call volumes)	9.341 billion mins/qtr

Source: Oftel Market Information Q2 2000/2001,

5.2.3. COST DATA

With regard to LRIC figures, we have had to rely mainly on estimates based on our understanding of the industry. Details of our assumptions regarding LRIC figures are summarised in Table 7.

Table 7: Incremental cost figures

<table>
<tr><th>Service</th><th>LRIC</th><th colspan="4">Comment</th></tr>
<tr><td>(1) Call termination on mobile network (ppm)</td><td>3.5</td><td colspan="4">Estimate; network costs only</td></tr>
<tr><td>(2) Retention on fixed-to-mobile calls (ppm)</td><td>3.07</td><td colspan="4">Average fixed-to-mobile price - average interconnection payment to MNOs (£524 million/4,752 million minutes in Q2 2000/01, from Oftel Market Information); marginal cost for mobile sector</td></tr>
<tr><td>(3) Mobile call origination (ppm)</td><td>3</td><td colspan="4">Estimate; network costs only</td></tr>
<tr><td>(4) Average call termination payment to fixed operators (ppm)</td><td>1.25</td><td colspan="4">Estimate; network costs only</td></tr>
<tr><td rowspan="5">Mobile originated call (ppm)</td><td rowspan="5">4.6</td><td colspan="4">Weighted average, using estimated share of total mobile originated call minutes</td></tr>
<tr><td></td><td>Weight</td><td></td><td></td></tr>
<tr><td>to fixed network</td><td>80%</td><td>4.25</td><td>(3) + (4)</td></tr>
<tr><td>to other mobile network</td><td>10%</td><td>6.5</td><td>(3) + (1)</td></tr>
<tr><td>On-net</td><td>10%</td><td>5.50</td><td>(3) + (1) – estimated savings of 1ppm for on-net traffic</td></tr>
<tr><td>Customer (£ per quarter)</td><td>18.75</td><td colspan="4">One quarter of estimated average of handset cost (£150) spread over two years</td></tr>
</table>

With regard to fixed costs that need to be recovered through mark-ups on these services, we have calculated the difference between total revenues (which we have assumed to be equal to total cost, assuming that the market for subscribers is effectively competitive) and the variable costs that would result from calibration quantities and the corresponding LRIC figures. This, of course, ignores the fact that 'true' LRIC may be higher, and correspondingly fixed costs may be lower, if one includes retail costs in the LRIC estimates. However, we should note that this should not substantially affect the relative size of the mark-ups as long as the relative size of LRICs remains largely unchanged. Similarly, the assumption of effective competition resulting in total costs being equal to total revenues is not crucial in the interpretation of our results: scaling back the level of fixed costs would not substantially change the relationship between mark-ups, even though it would obviously impact on their levels.

5.3. RESULTS

Table 8 presents the summary statistics for our bootstrap exercise. This shows that the Ramsey mark-up on fixed-to-mobile calls is significantly higher than the mark-up on mobile services. Here we are reporting the wholesale price of fixed-to-mobile calls (i.e. the call termination rate). Indeed, the 90% confidence interval lies one order of magnitude higher than the corresponding confidence intervals for subscription and mobile originated call mark-up confidence intervals.

Table 8: Summary statistics for Ramsey prices and mark-ups

	Mean	*Median*	*StdDev*	*90% Confidence Interval*	
Ramsey Prices					
Subscription	20.232	20.852	4.350	25.247	12.686
Mobile Originated Call	0.068	0.067	0.014	0.085	0.054
Fixed to Mobile call	0.276	0.268	0.065	0.394	0.189
Ramsey Mark-ups					
Subscription	7.9%	11.2%	23.2%	34.6%	32.3%
Mobile Originated Call	48.1%	46.6%	30.5%	83.7%	16.4%
Fixed to Mobile call	689.3%	665%	185.9%	1027.0%	441.1%
Mark-up Differences					
Fixed – Subscription	681.4%	652.0%	207.3%	1058.2%	411.1%
Fixed – Call	641.2%	617.4%	204.0%	1007.6%	362.7%
Call – Subscription	40.2%	37.9%	31.9%	72.8%	17.7%

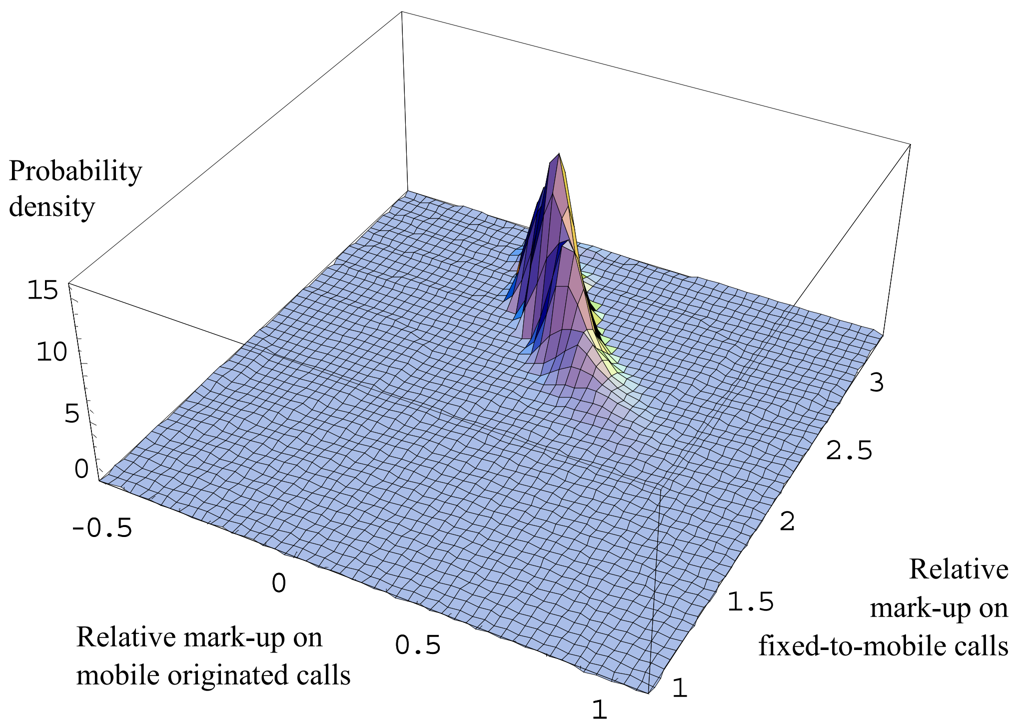
In order to show that Ramsey prices are significantly different from EPMU prices we need to reject the hypothesis that Ramsey mark-ups on all three services are equal. This would imply that pair-wise differences between mark-ups are zero. The final three rows of Table 8 shows that these differences are significantly different from zero.

In order to test for the joint significance of our rejection of the hypothesis that all mark-ups are equal we calculate the *relative* mark-ups on each of the three services, i.e. the mark-up on that service divided by the average mark-up across all three services.

A joint test of all three mark-ups being equal can now be reduced to a joint test for any two of these relative mark-ups being equal to one.

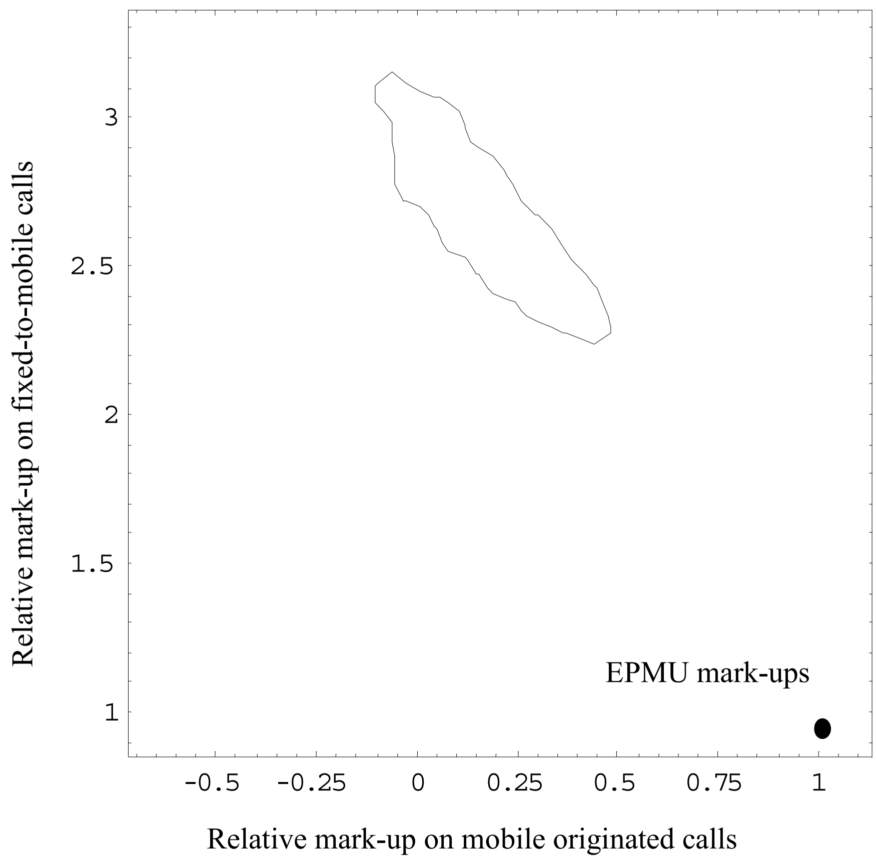
Figure 1 shows the density plot of the relative mark-ups on fixed-to-mobile and mobile originated calls. This demonstrates that the distribution of these relative mark-ups is unimodal and far away from EPMU prices (i.e. both relative mark-ups being equal to one).

Figure 1: Density of relative mark-ups on mobile originated and fixed-to-mobile calls



Moreover, Figure 2 shows the empirical 95% confidence region for the adjusted mark-ups, i.e. the likelihood contour within which lie 95% of all the individual observations. Clearly, this region does not include the point where both relative mark-ups are equal to one, which implies that Ramsey mark-ups are significantly different from EPMU mark-ups. Moreover optimal mark-ups on fixed-to-mobile calls are significantly higher than mark-ups on mobile originated calls at the 95% level.

Figure 2: 95% Confidence Interval for Test of Equal Mark-ups



6. CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

In this paper we have attempted to estimate Ramsey prices for mobile services in order to provide a rough benchmark for socially optimal charges. Our main results are:

- As expected on the basis of theoretical considerations, the structure of optimal charges is substantially different from those that would result if one applied a regime of equi-proportionate mark-ups to LRIC estimates over a wide range of demand parameter estimates. Thus, even with short aggregate time series we can obtain a robust conclusion that mark-ups on fixed-to-mobile calls should be considerably higher than mark-ups on mobile services (calls and subscriptions).

- Our model does not address the issue of network externalities beyond the impact of an increase in the number of mobile subscribers on the demand for fixed-to-mobile calls. This implies that at the same level of prices, more fixed-to-mobile calls would be made and that, therefore, more benefits would accrue to fixed line customers, but does not fully capture benefits that might accrue to infra-marginal customers because of the option value of being able to contact more customers on their mobiles.

- This paper has taken a normative approach, exploring what the optimal structure of prices should be rather than trying to establish whether current charging structures are close to this ideal. We have not tried to establish the extent to which one could expect the demand elasticities faced by individual mobile operators to be different from those on which the Ramsey solution is based. Therefore, our results do not indicate that MNOs are likely to, or should, set prices broadly in line with those that result from the Ramsey approach.

- In addition, we have not included other constraints that might potentially restrict MNOs pricing flexibility, such as the threat of call-back if mobile call charges and the price of fixed-to-mobile calls get too far out of line.

- We have not considered the impact of imperfect competition for subscribers. To the extent that mobile call termination may affect competition for customers there may be second-best issues in setting call termination rates that are not considered. Integrating existing models of oligopolistic interaction in the mobile market into this calibrated demand framework is a topic for further research.

- In this regard, our results must not be interpreted as saying that MNOs are currently setting socially optimal prices. However, what our results do strongly indicate is that, whatever the shortcomings of the current structure of charges, a move towards setting charges for one particular service element – call termination – at the level of LRIC + EPMU has the potential of resulting in far worse outcomes.

7. REFERENCES

1. ACCC (Australian Competition & Consumer Commission) (2000): *Pricing Methodology for the GSM Termination Service*, Draft Report, December.

2. Aldebert, M, Ivaldi, M and Roucolle, C (1999): "Telecommunications Demand and Pricing Structure: An Econometric Analysis", paper presented at the 7th International Conference on Telecommunications Systems, Dallas.

3. Armstrong, M. (1998), "Network Interconnection in Telecommunications", *The Economic Journal*, vol 108, May.

4. Bass, F (1990), "The Relationship between Diffusion Rates, Experience Curves and Demand Elasticities for Consumer Durable Technological Innovations", *Journal of Business* 53

5. Dineen, C (2000): "Demand Analysis and Penetration Forecasts for the Mobile Telephone Market in the UK", Paper presented at the ITU conference (www.its2000.org.ar/conference/dinnen.pdf

6. Dixon, R (1980), "Hybrid Corn Revised", *Econometrica* 48.

7. DotEcon (2001), *Estimation of Fixed-to-Mobile Price Elasticities,* paper prepared for BT, (see *http://www.dotecon.com/images/reports/elastftm.pdf).*

8. Gans, J S and King, S P (2000): "Mobile Network Competition, Customer Ignorance and Fixed-to-Mobile Call Prices", *Information Economics and Policy*, vol. 12.

9. Hendry, I (1972): "The Three Parameter Approach to Long Range Forecasting", *Long Range Planning* 51.

10. Jain, D and Rao, R (1990), "Effect of Price on the Demand for Durables: Modelling, Estimation and Findings", *Journal of Business and Economic Statistics* 8.

11. Laffont, J J and Tirole, J (2000): *Competition in Telecommunications,* MIT Press, Cambridge (Mass.).

12. Laffont, J J, Rey, P and Tirole, J. (1998a): "Network Competition I: Overview and Non-Discriminatory Pricing", *RAND Journal of Economics* 29 (1).

13. Laffont, J J, Rey, P and Tirole, J. (1998b), "Network Competition II: Price Discrimination", *RAND Journal of Economics* 29 (1).

14. Mahajan, V, Muller, E and Bass, F (1990), "New Product Diffusion Models in Marketing: A Review and Directions for Research", *Journal of Marketing* 54.

15. Monopolies and Mergers Commission (1998), *Cellnet and Vodafone*, Report on references under section 13 of the Telecommunications Act 1984 on the charges made by Cellnet and Vodafone for terminating calls from fixed-line networks.

16. Oftel (2001a): Charging Issues in the Regulation of Mobile Voice Termination Charges, A Paper for Discussion in the LRIC Working Group, 24 April.

17. Oftel (2001b): Review of Price Control on Calls to Mobiles, A Consultative Document issued by the Director General of Telecommunications, February.

18. Wright, J. (2000), "Competition and Termination in Cellular Networks", *mimeo,* University of Auckland.