Fixed-Mobile Substitution, Termination Rates, and Investments

Steffen Hoernig*, Marc Bourreau†, Carlo Cambini‡

5 August 2013

Abstract

We determine the equilibrium substitution between fixed and mobile calls and access when consumers differ in mobility. Call prices are affected by substitution possibilities if and only if this leads to price discrimination between heterogenous consumers. We show that high mobile termination rates increased adoption of mobile telephony, while low fixed termination rates led to reduced fixed access. [INCOMPLETE DRAFT]

Keywords: Network competition; fixed-mobile substitution; termination rates, investments.
JEL: L51, L92.

1 Introduction

The Issues at hand. New technologies and innovative service providers are often challenging the provision of traditional services. One of the most striking phenomena is the advent of mobile telephony and its impact on the traditional telephony service over fixed lines. Only three decades ago, fixed-line operators provided all communications needs over their respective

*Corresponding author. Nova School of Business and Economics, INOVA, Universidade Nova de Lisboa; CEPR, UK. Email: shoernig@novasbe.pt. Postal address: Nova SBE, Campus de Campolide, 1099-032 Lisboa, Portugal. tel. +351-213801600, fax +351-213870933. Acknowledges funding through grant PTDC/EGEECO/100696/2008 of the Ministry of Science and Technology.

†Telecom ParisTech, Department of Economics and Social Sciences, and CREST-LEI, Paris. Email: marc.bourreau@telecom-paristech.fr.

‡Politecnico di Torino, DIGEP; EUI - Florence School of Regulation. Email: carlo.cambini@polito.it.

networks, but in the last 20 years mobile telephony has significantly disrupted the historical market structure. All over the world, wireless services have recorded substantial growth in terms of subscribership, revenue, and usage, and despite recent difficult economic times, the number of mobile subscribers and usage continues to grow.

Much of the enormous success of the mobile sector is due to intermodal competition, or more specifically to fixed-mobile substitution. Major technological advances and cost reductions have enabled mobile carriers to decrease the difference between fixed and mobile pricing levels, which has allowed them to become strong competitors to traditional fixed providers. At the same time, both fixed and mobile telephony have been subject to regulatory intervention, but to different degrees: While fixed telephony operators' retail and wholesale prices (i.e. termination rates) tended to be strongly regulated at cost, for mobile operators only termination rates were eventually regulated, and until recently at values far above marginal cost.

While empirical studies have attempted to quantify fixed-mobile substitution (see the survey by Vogelsang, 2010, as well as our review in the next paragraph), there is a lack of theoretical investigation on how to model consumers' mobility preference and its effect on call and access substitution. This paper tries to fill this gap.

In particular, we consider a model with three independent but interconnected operators, one fixed and two mobile networks. Our key novelty is the construction of the demand side. Consumers have variable mobility needs, i.e. a different probability that they are on the move. Depending on their mobility, consumers choose whether to single- or multihome, i.e. whether to subscribe to a fixed or a mobile network, or to both. Moreover, in our paper, differently from previous work, fixed and mobile are simultaneously substitutes and complements: They are complements because even owners of a fixed line benefit from having a mobile subscription, by being able to make calls when they are not at home; they are substitutes because when both networks are available only the cheaper type of call will be used.

These assumptions are particularly realistic and in line with recent evidence from the market. The association of European Telecom Regulators (BEREC, 2011) reported that although the share of mobile only households increased and fixed-only households decreased, dual access (both fixed and mobile telephone access) is still the most common situation in Europe (62% of households, on average) and is not declining.[1] In a recent report, the OECD (2012) also concludes that fixed and mobile networks are both complements

[1]Based on the 2011 E-communication household survey, the number of households having at least one mobile is rather high and homogeneous – from 82% to 96% (average 89%) – across Europe. On the other hand, fixed line penetration is extremely heterogeneous: fixed

and substitutes.

The aim of our paper is to analyze the impact of varying levels of termination charges on consumers' subscription decision of different technologies. The key question then is whether the different regulatory treatments of termination of fixed and mobile networks affect the development on fixed and mobile adoptions. Our results show that high mobile termination rates increase adoption of mobile phones, while low fixed termination rates lead to reduced fixed access.

Literature Review There exists a sizeable economic literature on the relationship between fixed and mobile telephony and on the role of fixed-to-mobile termination charges.

Wright (2002) considers FTM calls with a focus on mobile termination rates, while others (e.g. Valletti and Houpis, 2005) analyze how socially optimal FTM termination charges would depend on the magnitude of network externalities, the intensity of competition in the mobile sector, and the distribution of customer preferences. These papers however does not consider the role of fixed-mobile substitution.

Armstrong and Wright (2009) and Hausman (2012) analyze the role of call substitution and discuss voluntary vs. regulated MTR setting. Both papers show that substitution between FTM and MTM calls weakens the competitive bottleneck of call termination and brings the equilibrium charge closer to the efficient level. Hence, the welfare gains from regulating MTR are smaller, while private incentives for MTR setting are sufficient to avoid excessively high interconnection prices. We depart from these papers since we analyze both *access* and *call* substitution and how termination charges affect technology adoption.

Closest to our paper is Hansen (2006), who also investigates fixed-mobile access substitution in a model with competition in the mobile market and subscribers with varying mobility. Contrary to our analysis, though, he does not model how mobility interacts with the calls that a consumer can make (e.g., while not at home no fixed calls can be made), and does not analyze the market structure with three customer groups we focus on, with mobile- or fixed-only consumers and others who have both. We believe this is the most realistic and thus practically relevant market structure. User mobility is also present in Valletti (2003) but in a "mobile-only" model with consumers moving from an urban to a rural area and seeking access to mobile services

access is very high in countries such as Sweden (98%), the Netherlands (89%) and France (87%) whereas no more than 17% of the Czech households are connected. Mobile-only households range from 2% to 81%, while dual access from 15% to 94%.

conditional on the coverage mobile operators have in different areas.

Though applied to a different setting, the game-theoretic structure of our paper is also similar to de Bijl and Peitz (2009), who analyze the effect of access and retail price regulation on the adoption of Voice over IP (VoIP). In both settings, consumers first choose which technology to adopt. Given these adoption decisions firms compete in the respective markets.

On the policy side, Bomsel et al. (2003) focus on the simultaneous impact of fixed and mobile interconnection rates as they apply to fixed-to-mobile or mobile-to-fixed traffic. The authors show that the scale of the transfer as a result of high mobile termination charges for fixed to mobile calls from fixed networks and their customers has, over the five years 1998-2002, amounted to 19 billion Euros in France, Germany and the UK. According to these authors, the effect of this transfer has been to injure fixed customers and their operators, is likely to have damaged competition in the fixed market, and distorted competition between fixed and mobile operators.

Our paper is theoretical, but it is important to review also the relevant empirical evidence on fixed-mobile substitution (see the surveys by Woroch, 2002; and Vogelsang, 2010). The evidence to date for fixed-mobile substitution is rather mixed and shows that call substitution is increasing while access substitution is generally modest (Vogelsang, 2010). For example, Rodini et al. (2003), using data from US, show that households' subscription to second fixed lines and mobile service are access substitutes, while Ward and Woroch (2005 and 2010) find substantial substitutability between fixed and mobile subscriptions. More recently, new studies provide much stronger evidence on fixed mobile call substitution. Briglauer et al. (2011) find that, at least for Austria, fixed and mobile calls are strong substitutes while access substitution is rather weak. Ward and Zheng (2012), using panel data from China, find that fixed and mobile telephony services have become fairly strong substitutes both for usage and subscriptions. Barth and Heimeshoff (2012a,b), using panel data on EU27 countries, show modest substitution effects on fixed and mobile subscriptions, while the estimated cross-price elasticity of the mobile price on fixed line call demand is relatively large compared to previous studies. Finally, Grzybowski (2012) analyses substitution between access to fixed-line and mobile telephony in the European Union and finds that decreasing prices for mobile services increase the share of mobile-only households and decrease the shares of fixed-only and fixed-plus-mobile households which suggests substitution between fixed-line and mobile connections.

Note that none of these empirical studies present evidence on the impact of FTR and/or MTR on consumers' subscription decisions. Hence our paper provides new testable predictions for future empirical work on fixed-mobile substitution.

2 Model and Pricing Equilibrium

2.1 Setup

Consumers and firms. In our basic setting, we assume that there two mobile networks and one monopoly fixed network. The latter is regulated such that its call prices are set at cost and its total profits are zero. This setting is intended to capture the first phase of the development of mobile markets, with a monopoly fixed network and high mobile termination rates (MTRs). We consider competition in the fixed market, together with low MTRs, below in Section 4.

There is a total mass 1 of consumers, who can subscribe to some mobile network and / or the fixed network. We denote them correspondingly as mobile-only (M), fixed-mobile (FM) and fixed-only (F) subscribers. The mobile market is modeled à la Hotelling, with network 1 at location $x_1 = 0$ and network 2 at $x_2 = 1$, and subscriber numbers $\mu_i \geq 0$, where $i = 1, 2$. A subscriber located at $x \in [0, 1]$ has a disutility of not subscribing to his preferred variety of $t |x - x_i|$, where $t > 0$. If the price of a call is p_I for index I, his indirect utility is $v_I = v(p_I)$ with call duration $q_I = -v'(p_I)$.

Each consumer has "mobility" $\lambda \in [0, 1]$, i.e. λ is the probability that he is on the move, where he only has access to his mobile phone and can neither make nor receive calls via a fixed line. On the other hand, with probability $1 - \lambda$ he is at home, where he may have access to a fixed and a mobile phone, and chooses whichever is cheaper if he has both. Consumers are on the move or at home independently of each other,[2] and calling patterns are balanced. Contrary to Hoernig et al. (2013b), we assume that consumers are heterogeneous: Mobility λ is distributed on $[0, 1]$ with positive density h and distribution function H. We assume that each consumer's mobility λ and location on the Hotelling line x are independent of each other, and posit the following timing: Knowing λ, consumers first choose between subscribing to a fixed or mobile contract, or both, taking into account their expectations about the equilibrium outcome in the mobile market; then they learn x and choose between mobile operators if they want a mobile contract.[3]

Let $0 < \lambda_* < \lambda^* < 1$. In the following we will consider market outcomes where all subscribers expect that those with $\lambda < \lambda_*$ only subscribe to the fixed network, those with $\lambda_* \leq \lambda \leq \lambda^*$ to the fixed and a mobile network,

[2] Extension section: check with correlation.

[3] This timing assumption implies simple expressions for market shares and keeps the analysis technically feasible. It can be justified by considering the choice of having a mobile phone as a more long-run decision than that whether to subscribe to one or the other mobile operator.

and those with $\lambda > \lambda^*$ only to a mobile network. Their respective numbers are

$$\mu^x = H(\lambda_*), \mu^{mx} = H(\lambda^*) - H(\lambda_*), \mu^m = 1 - H(\lambda^*). \tag{1}$$

For each of these groups, the expected number of people on the move is

$$\lambda^x = \int_0^{\lambda_*} \lambda dH(\lambda),\ \lambda^{mx} = \int_{\lambda_*}^{\lambda^*} \lambda dH(\lambda),\ \lambda^m = \int_{\lambda^*}^{1} \lambda dH(\lambda). \tag{2}$$

Mobile networks have a fixed cost per subscriber f, marginal costs of origination and termination c_o and c_t, and on-net costs $c = c_o + c_t$. The mobile termination rate, applied regardless of whether calls originate on mobile or fixed networks, is a. The fixed network, on the other hand, has fixed cost f_x, marginal costs c_{xo} and c_{xt}, on-net costs $c_x = c_{xo} + c_{xt}$, and termination rate a_x. We assume the following ordering of the marginal costs of calls:

$$c_x < c_o + a_x < c_o + \frac{c_t + a}{2} < c_{xo} + a. \tag{3}$$

Given that marginal costs and termination rates on fixed networks tend to be far below those of mobile networks, the only actually restrictive assumption is the last one, i.e. that mobile termination rates are so high that calls from fixed to mobile networks have higher perceived marginal costs than mobile-to-mobile calls, i.e. $a > c_t + 2(c_o - c_{xo})$.[4]

Tariffs and surplus. Mobile network i charges a tariff (F_i, p_i, p_{ix}), where F_i is a monthly fixed fee, and p_i and p_{ix} are the mobile-to-mobile and mobile-to-fixed per-minute call prices.[5] The fixed network offers a tariff (F_x, p_x, p_{xm}), where F_x is its monthly fixed fee, p_x is its on-net price, and p_{xm} is the fixed-to-mobile per-minute call price. For now we also postulate (and later confirm), that the following ordering of prices holds:

$$p_x < p_{ix} < p_i < p_{xm}. \tag{4}$$

Note that (4) is consistent with all or most of equilibrium prices being equal to marginal cost, ordered by assumption (3).

Apart from the surplus related to calls, subscribers obtain different amounts of access surplus depending on what they subscribe to. If they only subscribe to a mobile network or the fixed network, their subscription surplus is A_m or

[4] Historically correct, but not in the future, maybe. Thus Extension section: low MTR, so that FTM calls are cheaper than MTM calls.

[5] We assume a uniform MTM call price, ruling out tariff-mediated network effects, in order to concentrate on the effects of interconnection between fixed and mobile networks.

A_x, respectively; if they subscribe to both the fixed and a mobile network, it is A_{mx}.

When an FM-subscriber of network i is on the move, the above order of prices implies that it is cheaper to make MTF calls instead of MTM calls when receivers are at home ($p_{ix} < p_i$), thus MTM calls are only made when receivers are themselves on the move.[6] When at home, the same subscriber can use both the fixed and mobile phones. He uses his fixed phone to call other users at home ($p_x < p_{ix}$) and his mobile phone to call others on the move ($p_i < p_{xm}$). Given mobility λ, the resulting expected surplus of both subscribing to the fixed network and to mobile network i is

$$w_i^{mx}(\lambda) = A_{mx} - F_i - F_x + (\mu^m + \lambda^{mx}) v_i + \phi [\lambda v_{ix} + (1 - \lambda) v_x]. \tag{5}$$

First we have gross subscription surplus minus both fixed fees, then the surplus of calling M-clients and FM-clients when the latter are on the move. Lastly, there is the surplus from calling the

$$\phi = (\mu^{mx} - \lambda^{mx} + \mu^x - \lambda^x) = \int_0^{\lambda^*} (1 - \lambda) \, dH(\lambda) \tag{6}$$

FM- and F-clients when they are at home, either calling from the road with probability λ or from home. The last term implies substitution to cheaper FTF on-net calls when possible.

An M-client makes all calls with his mobile phone, with corresponding surplus

$$w_i^m = A_m - F_i + (\mu^m + \lambda^{mx}) v_i + \phi v_{ix}, \tag{7}$$

which does not depend on λ. Similarly, an F-client obtains surplus

$$w^x(\lambda) = A_x - F_x + (1 - \lambda) [(\mu^m + \lambda^{mx}) v_{xm} + \phi v_x]. \tag{8}$$

The latter is the only group that makes FTM calls, and contrary to the other customers only has access to a phone when they are at home.

Market shares. Now we consider the choice of mobile operator after consumers have learned their location x. Here and in the following let $i, j = 1, 2$ and $j \neq i$. From the point of view of network i, the indifferent FM-subscriber with mobility λ, $y_i^{mx}(\lambda)$, is given by

$$y_i^{mx}(\lambda) = \frac{1}{2} + \frac{w_i^{mx}(\lambda) - w_j^{mx}(\lambda)}{2t}. \tag{9}$$

[6] We can imagine that the caller first tries the receiver's fixed line and then calls him on his mobile if he is not at home.

Its number of subscribers in the FM-group, and those of the latter who are on the move, are

$$\mu_i^{mx} = \int_{\lambda_*}^{\lambda^*} y_i^{mx}(\lambda)\, dH(\lambda), \ \lambda_i^{mx} = \int_{\lambda_*}^{\lambda^*} \lambda y_i^{mx}(\lambda)\, dH(\lambda). \tag{10}$$

We define y_i^m similarly, which results in the simpler $\mu_i^m = \mu^m y_i^m$, $\lambda_i^m = \lambda^m y_i^m$ and $\mu_i = \mu_i^{mx} + \mu_i^m$, which we can state explicitly as

$$\begin{aligned} \mu_i &= (\mu^m + \mu^{mx}) \left(\frac{1}{2} + \frac{F_j - F_i + (\mu^m + \lambda^{mx})(v_i - v_j)}{2t} \right) \\ &\quad + (\mu^m + \lambda^{mx}) \frac{\phi (v_{ix} - v_{jx})}{2t}. \end{aligned} \tag{11}$$

For $k \in \{m, mx\}$, we have $\mu_1^k + \mu_2^k = \mu^k$, and $\mu_1 + \mu_2 = \mu^m + \mu^{mx} = 1 - \mu^x$. [**sh: put figure here**]

Profits. The profits of mobile firm i are given by

$$\begin{aligned} \pi_i &= \mu_i \left\{ F_i - f + \left[(\mu^m + \lambda^{mx})(p_i - c) - \left(\mu_j^m + \lambda_j^{mx} \right)(a - c_t) \right] q_i \right\} \\ &\quad + (\mu_i^m + \lambda_i^{mx}) \phi (p_{ix} - c_o - a_x) q_{ix} \\ &\quad + (\mu_i^m + \lambda_i^{mx})(a - c_t) \left[\mu_j q_j + (\mu^x - \lambda^x) q_{xm} \right]. \end{aligned} \tag{12}$$

On the first line we have the profits due to fixed fees and calls to other mobiles, on the second line the profits from calls to the fixed network, and on the last line termination profits.

For the fixed network, profits are

$$\begin{aligned} \pi_x &= (\mu^x + \mu^{mx})(F_x - f_x) + \phi^2 (p_x - c_x) q_x \\ &\quad + (\mu^x - \lambda^x)(\mu^m + \lambda^{mx})(p_{xm} - c_{xo} - a) q_{xm} \\ &\quad + \phi (a_x - c_{xt}) \left[(\mu_1^m + \lambda_1^{mx}) q_{1x} + (\mu_2^m + \lambda_2^{mx}) q_{2x} \right]. \end{aligned} \tag{13}$$

Again, subscription profits are on the first line, together with those from on-net calls. On the second line we have calls to mobiles, and termination profits are on the last line.

Subscription decisions. At the previous stage, where consumers have not yet learned their location x, the expected utility of consumers in group $k \in \{m, mx\}$ is

$$\begin{aligned} \bar{w}^k &= y_1^k w_1^k - \int_0^{y_1^k} tz dz + y_2^k w_2^k - \int_0^{y_2^k} tz dz \\ &= y_1^k w_1^k + y_2^k w_2^k - t \frac{\left(y_1^k\right)^2 + \left(y_2^k\right)^2}{2}. \end{aligned} \tag{14}$$

If subscribers expect a symmetric equilibrium in the mobile market, this becomes simply $\bar{w}^k = w_i^k - \frac{t}{4}$. All consumers with λ such that $\bar{w}^m > \bar{w}^{mx}(\lambda)$ then choose to not have a fixed phone, implying that λ^* is given by $\bar{w}^m = \bar{w}^{mx}(\lambda^*)$, or,

$$F_x = A_{mx} - A_m + \phi(1-\lambda^*)(v_x - v_{ix}). \tag{15}$$

We assume that λ^* is large enough so that $\phi(1-\lambda^*)$ is decreasing in λ^*, which implies that a higher fixed fee F_x increases the number of mobile-only subscribers, i.e. lowers λ^*.

Equally, all consumers with $w^x(\lambda) > \bar{w}^{mx}(\lambda)$ choose to only have a fixed phone. Thus λ_* is given by $w^x(\lambda_*) = \bar{w}^{mx}(\lambda_*)$, or

$$F_i = A_{mx} - A_x + (\mu^m + \lambda^{mx})(v_i - (1-\lambda_*)v_{xm}) + \phi\lambda_* v_{ix} - \frac{t}{4}. \tag{16}$$

Here we assume that λ_* is small enough, so that the right-hand side is increasing in λ_*, implying that higher F_i increases λ_*, i.e. increases the number of fixed-only customers.[7]

Consumer surplus and welfare. Expected consumer surplus is given by

$$CS = \int_0^{\lambda_*} w^x(\lambda)\, dH(\lambda) + \int_{\lambda_*}^{\lambda^*} \bar{w}^{mx}(\lambda) dH(\lambda) + \mu^m \bar{w}^m,$$

and total welfare is

$$W = CS + \pi_1 + \pi_2 + \pi_x.$$

2.2 Equilibrium Tariffs and Subscriber Numbers

We now solve for the (symmetric) equilibrium in the mobile market, taking consumers' decision of buying a mobile phone and / or adhering to the fixed network, i.e. λ_* and λ^*, as given. The standard procedure of maximizing networks' profits over call prices while holding subscriber numbers constant fails because of "composition effects": Fixed fees and MTF prices enter μ_i, μ_i^{mx} and λ_i^{mx} with varying relative weights. Thus adjusting F_i to hold, say, μ_i constant after a change in p_{ix} does not annul the changes in μ_i^{mx} and λ_i^{mx}. The correct procedure, as applied in the proof of the following result, is to maximize simultaneously over the whole tariff (F_i, p_i, p_{ix}). Let $L^{mx} = \int_{\lambda_*}^{\lambda^*} \lambda^2 dH(\lambda)$, which captures the mobility dispersion of FM-consumers.

[7] For a uniform distribution, $h(\lambda) = 1$, these conditions imply that $\lambda^* > 0.423$ and that λ_* is close enough to zero.

Proposition 1 *Given* $0 < \lambda_* < \lambda^* < 1$*, symmetric mobile equilibrium tariffs are given by:*

1. *A mobile-to-mobile call price equal to average marginal cost,*

$$p_i = c + \frac{1}{2}(a - c_t); \tag{17}$$

2. *a mobile-to-fixed call price below marginal cost if and only if the mobile termination rate is above cost,*

$$p_{ix}^* = c_o + a_x - (a - c_t)\frac{\Phi\left[(\mu^m + \mu^{mx})\, q_i + (\mu^x - \lambda^x)\, q_{xm}\right]}{\Phi\phi q_{ix} - tq_{ix}'/q_{ix}}, \tag{18}$$

where

$$\Phi = \left(\frac{\mu^m + L^{mx}}{\mu^m + \lambda^{mx}} - \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}}\right) > 0;$$

3. *fixed fees equal to*

$$\begin{aligned} F_i^* \;&=\; f + t - \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}}\phi\,(p_{ix} - c_o - a_x)\, q_{ix} \\ &\quad - (\mu^m + \lambda^{mx})(a - c_t)\left(\frac{q_j}{2} + \frac{\mu^x - \lambda^x}{\mu^m + \mu^{mx}} q_{xm}\right). \end{aligned} \tag{19}$$

Equilibrium profits are

$$\pi_i^* = \frac{\mu^m + \mu^{mx}}{2} t. \tag{20}$$

Profits and the MTM call price p_i have the standard form for uniform tariffs, i.e. transport cost times the subscriber number and perceived average marginal cost, respectively (Armstrong 1998 and Laffont, Rey and Tirole 1998a).

On the other hand, the MTF call price p_{ix} is set below marginal cost and the fixed fee is increased. This pricing structure allows networks to charge more to its infra-marginal customers, while compensating its marginal ones through a lower MTF price. From (7) and (5) we can see that the latter marginal customers are the mobile-only subscribers, who have no opportunity to substitute toward FTF calls. These customers receive more incoming calls, and therefore are relatively more valuable to have on one's own rather than the rival's network when $a > c_t$. This is borne out by the fact that the distortion in p_{ix} disappears when mobile termination is set at cost, i.e.

$a = c_t$. Thus we find that the *combination of call substitution and customer heterogeneity* gives rise to a distorted usage pricing structure.

For a regulated monopoly fixed network, cost-based call pricing and a zero-profit constraint imply, given a symmetric equilibrium in the mobile market,

$$p_x = c_x,\ p_{xm} = c_{xo} + a,\ F_x = f_x - \phi \frac{\mu^m + \lambda^{mx}}{\mu^x + \mu^{mx}} (a_x - c_{xt})\, q_{ix}. \tag{21}$$

3 The Effects of Mobile Termination Rates

3.1 Fixed-Mobile Substitution

After substituting F_i and F_x from (19) and (21), conditions and (15) and (16) become, for λ^*,

$$0 = A_{mx} - f_x - A_m + \phi \left\{ (1-\lambda^*)(v_x - v_{ix}) + \frac{\mu^m + \lambda^{mx}}{\mu^x + \mu^{mx}} (a_x - c_{xt})\, q_{ix} \right\}, \tag{22}$$

and, for λ_*,

$$\begin{aligned} 0 \;=\;& A_{mx} - f - A_x - \frac{5}{4}t + \phi \lambda_* v_{ix} + (\mu^m + \lambda^{mx})(v_i - (1-\lambda_*)\, v_{xm}) \\ & + (\mu^m + \lambda^{mx})(a - c_t) \left(\frac{1}{1 - \Phi \phi q_{ix}^2 / t q_{ix}'} \left[q_i + \frac{\mu^x - \lambda^x}{\mu^m + \mu^{mx}} q_{xm} \right] - \frac{q_i}{2} \right). \end{aligned} \tag{23}$$

Condition (22) determines the cut-off between mobile-only and FM-customers by equating the incremental surplus from subscribing also to the fixed network, of the consumer with mobility λ^*, to zero. This incremental surplus consists of the net increase in access surplus $A_{mx} - f_x - A_m$, the benefit of call substitution $\phi(1-\lambda^*)(v_x - v_{ix})$, and a share of the fixed network's termination profits that are handed over via its fixed fee. Consumers with larger mobility, $\lambda > \lambda^*$, obtain smaller benefits from call substitution, and thus from having a fixed line, while consumers with lower mobility will want to have both phones in order to benefit from call substitution.

Condition (23) determines the cut-off λ_* between fixed-only and FM-customers in a similar manner. Here the incremental access surplus is $A_{mx} - f - A_x - \frac{5}{4}t$ and includes both expected transport cost and the effect of transport cost on fixed fees. The incremental benefits from calls is given by the possibility of making calls while on the road and the substitution of cheaper MTM for FTM calls, while the terms on the second line again comprise a share of termination profits transmitted via lower fixed fees. In this case, consumers with lower mobility, $\lambda < \lambda_*$, simultaneously have smaller benefits from being able to make calls on the road and more access to a cheap fixed phone, and thus opt not have a mobile one.

A necessary condition for an interior outcome $0 < \lambda_* < \lambda^* < 1$ is that the fixed-mobile access surplus is not too high, i.e.

$$A_{mx} < \min\left\{A_m + f_x, A_x + f + \frac{5}{4}t\right\},$$

which we will assume to hold in the following. This condition indicates that what drives consumers' decision to have both a fixed and mobile phone, rather than just one or the other, is both the possibility of making calls on the road and the substitution to cheaper fixed calls at home, over and above the pure benefit of mobile access.

In general, expressions (22) and (23) jointly define λ_* and λ^*as a function of the termination rates a and a_x.

Since traditionally fixed networks had their termination rate regulated at cost,

Second, if the fixed termination rate is set at cost, condition (22) is independent of both a and λ_*. Thus in this case λ^* does not depend on the mobile termination rate. Thus we have the following result:

Proposition 2 *1. If fixed termination is priced at cost, the total number of fixed customers λ^* is defined by*

$$\phi\left(1 - \lambda^*\right) = \frac{A_m - (A_{mx} - f_x)}{v_x - v_{ix}}.$$

It is increasing in the incremental social surplus of fixed access $A_{mx} - f_x - A_m$ and in the MTF price p_{ix}, and decreasing in the FTF price p_x.

2. The total number of mobile customers $(1 - \lambda_*)$ is increasing in the incremental social surplus of mobile access and the mobile termination rate, and increasing in product differentiation in the mobile market (at least while a is close enough to cost). ***[sh: check floor!]***

Proof. 1. By assumption, $\phi\left(1 - \lambda^*\right)$ is decreasing in λ^* over the relevant range. Thus a lower value of the right-hand side, due to higher $A_{mx} - f_x - A_m$ or p_{ix}, or lower p_x, increases λ^*.

2. For a close enough to c_t, by assumption the right-hand side of (23) increases in λ_* over the relevant range, while it is increasing in $A_{mx} - f - A_x$ and a, and decreasing in t. Thus λ_* increases with lower $A_{mx} - f - A_x$ and a, and with higher t. ■

[sh: comment on these findings.]

To complement these findings for a mobile termination rate close to cost, we also provide some numerical simulations for higher termination rates. We have made the following assumptions: λ is uniformly distributed on $[0,1]$, $q(p) = 1 - p$, $c_o = c_t = 0.2$, $c_{xo} = c_{xt} = 0.1$, $A_{mx} - f_x - A_m = -0.012$, and $A_{mx} - f - A_x - \frac{5}{4}t = -0.05$. Varying the termination rates a (with $a \geq c_t + 2(c_0 - c_{xo}) = 0.4$) and a_x, we find the following pairs λ_*, λ^*:

$a \backslash a_x$	0.10	0.12	0.14	0.16
0.40	0.12,0.63	0.13,0.82	0.14,0.90	0.15,0.96
0.45	0.05,0.63	0.08,0.82	0.08,0.91	0.09,0.96
0.50	0.00,0.63	0.02,0.82	0.03,0.91	0.04,0.96

Table 1: Equilibrium values of λ_* and λ^*.

Table 1 shows that the fixed termination rate a_x has a weak influence on λ_*, but a strong influence on λ^*: A higher fixed termination rate strongly reduces the number of consumers who only hold a mobile phone. On the other hand, the mobile termination rate a has little effect on the decision whether to give the fixed phone (λ^* almost does not change with a), but a strong effect on the decision whether to take up a mobile-phone contract: Higher a strongly decreases λ_*.

These simulation results indicate that the regulatory policy in effect during the last decade furthered fixed-mobile access substitution through two separate channels: High mobile termination rates significantly increased take-up of mobile services, while low (cost-based) fixed termination rates incentivized customers to drop their fixed connection.

3.2 Network Investments

Simple model: investment in fixed network is given, increases $A_{mx} - f_x - A_m$ but increases fixed fee F_x (by less, otherwise investment lowers welfare).

mobile market: profits are $t*$ subscriber numbers. Assume JOINT investment, so only issue is how termination rates influence effect of investment (interaction in (23). Assume that mobile investment raises $A_{mx} - f - A_x$.

First conclusion: λ^* only affected by fixed investment.

question: how do termination rates influence incentives for investments in mobile market, i.e. how do investments interact with $d\lambda_*/da$? i.e. what is $d^2\lambda_*/dad\,(A_{mx} - f - A_x)$.

4 Extensions

4.1 Low MTRs

Mobile termination rates close to cost? with $a < c_t + 2(c_o - c_{xo})$ substitution patterns change, since it will be cheaper to make FTM calls than mobile (uniform priced) calls. Result: at home only fixed phone will be used.

4.1.1 Competition in the fixed market

[sh: needed? this should only be relevant for the case with low MTR anyway] If on the other hand we have two symmetric fixed networks in perfect competition with each other then a symmetric equilibrium FTM call prices are identical to (21), but with $a_x > c_{xt}$ the FTF call price and fixed fee change: Call prices are chosen to maximize total surplus and are thus equal to cost, which in this case implies $p_x = c_x + (a_x - c_{xt})/2$; and the fixed fee then includes FTF termination profits:[8]

$$F_x = f_x - \frac{\phi^2}{4}(a_x - c_{xt})\, q_x - \phi \frac{\mu^m + \lambda^{mx}}{\mu^x + \mu^{mx}}(a_x - c_{xt})\, q_{ix}.$$

With Hotelling competition and transport cost parameter τ, we should get

$$F_x = f_x + \tau - \frac{\phi^2}{4}(a_x - c_{xt})\, q_x - \phi \frac{\mu^m + \lambda^{mx}}{\mu^x + \mu^{mx}}(a_x - c_{xt})\, q_{ix}.$$

(plus additional terms in $\bar{w}^x$ and $\bar{w}^{mx}$

4.2 Price Discrimination Between On- and Off-net Calls

PD?, but then with variable number of symmetric mobile networks. ready-steady-go! now call externality matters, but we assume there is none; effects qualitatively the same.

5 Conclusions

Mobile telephony has been a tremendous success in the last two decades, making large inroads into the fixed telephony market. Subscribers in many countries now use their mobiles more than their fixed lines, and quite often

[8] With imperfect competition a la Hotelling, we would have to add the transport cost parameter in the fixed market to the resulting fee, similar to (19) below. Nothing else changes.

disconnect the latter. We have presented a model that captures this development and substitution at subscription and call level. Our results show that call substitution does not change retail pricing incentives unless customer heterogeneity makes it worthwhile to discriminate between customers with different substitution possibilities. Termination rates do have an effect on subscription substitution and fixed disconnection, but in more specific manner than is usually postulated. More precisely, a higher termination rate for a type of network (fixed or mobile) increases the number of subscribers to this type of network, but has little effect on disconnections on the other network. Rather, it determines the number of customers who subscribe to both. Thus the long-standing policy of setting low termination rates on fixed networks has increased the number of disconnections, and high ones on mobile networks have led to a stronger increase in mobile customers.

Future research will contemplate the transition to cost-based mobile termination and competition in the fixed market on the one hand, and investment incentives on the other.

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6 Appendix

Proof of Proposition 1: Firm i's profits are

$$\begin{aligned}\pi_i &= \mu_i \left\{F_i - f + \left[(\mu^m + \lambda^{mx})(p_i - c) - \left(\mu_j^m + \lambda_j^{mx}\right)(a - c_t)\right] q_i\right\} \\ &\quad + \left(\mu_i^m + \lambda_i^{mx}\right)\left(\phi\left(p_{ix} - c_o - a_x\right) q_{ix} + (a - c_t)\left[\mu_j q_j + (\mu^x - \lambda^x) q_{xm}\right]\right).\end{aligned}$$

From (9) and (10), subscriber numbers can be expressed explicitly as

$$\begin{aligned}\mu_i &= (\mu^m + \mu^{mx})\left(\frac{1}{2} + \frac{F_j - F_i + (\mu^m + \lambda^{mx})(v_i - v_j)}{2t}\right) \\ &\quad + (\mu^m + \lambda^{mx})\frac{\phi(v_{ix} - v_{jx})}{2t}, \\ \mu_i^m &= \mu^m\left(\frac{1}{2} + \frac{F_j - F_i + (\mu^m + \lambda^{mx})(v_i - v_j) + \phi(v_{ix} - v_{jx})}{2t}\right), \\ \lambda_i^{mx} &= \lambda^{mx}\left(\frac{1}{2} + \frac{F_j - F_i + (\mu^m + \lambda^{mx})(v_i - v_j)}{2t}\right) + L^{mx}\frac{\phi(v_{ix} - v_{jx})}{2t},\end{aligned}$$

where $L^{mx} = \int_{\lambda_*}^{\lambda^*} \lambda^2 dH(\lambda)$. From this we obtain the derivatives

$$\begin{aligned}\frac{\partial \mu_i}{\partial p_i} &= -\frac{(\mu^m + \mu^{mx})(\mu^m + \lambda^{mx}) q_i}{2t}, \\ \frac{\partial \mu_i}{\partial p_{ix}} &= -\frac{(\mu^m + \lambda^{mx})\phi q_{ix}}{2t}, \ \frac{\partial \mu_i}{\partial F_i} = -\frac{(\mu^m + \mu^{mx})}{2t}, \\ \frac{\partial \mu_i^m}{\partial p_i} &= -\frac{\mu^m(\mu^m + \lambda^{mx}) q_i}{2t}, \frac{\partial \mu_i^m}{\partial p_{ix}} = -\frac{\mu^m \phi q_{ix}}{2t}, \frac{\partial \mu_i^m}{\partial F_i} = -\frac{\mu^m}{2t}, \\ \frac{\partial \lambda_i^{mx}}{\partial p_i} &= -\frac{\lambda^{mx}(\mu^m + \lambda^{mx}) q_i}{2t}, \frac{\partial \lambda_i^{mx}}{\partial p_{ix}} = -\frac{L^{mx}\phi q_{ix}}{2t}, \frac{\partial \lambda_i^{mx}}{\partial F_i} = -\frac{\lambda^{mx}}{2t}.\end{aligned}$$

The corresponding derivatives of μ_j, μ_j^m and λ_j^{mx} with respect to p_i, p_{ix} and F_i have the opposite signs. The first-order conditions for maximizing profits

π_i over p_i, p_{ix} and F_i, can be written as follows, for symmetric $\mu_i = \frac{\mu^m + \mu^{mx}}{2}$ and $(\mu_i^m + \lambda_i^{mx}) = \frac{\mu^m + \lambda^{mx}}{2}$, and letting

$$T = \left\{ F_i - f + (\mu^m + \lambda^{mx}) \left[p_i - c - \frac{a - c_t}{2} \right] q_i \right\}.$$

For p_i,

$$\begin{aligned} T &= t + t \left[p_i - c - \frac{a - c_t}{2} \right] \frac{q_i'}{q_i} - \frac{(\mu^m + \lambda^{mx})}{2} (a - c_t) q_i \qquad (24) \\ &- \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}} (\phi (p_{ix} - c_o - a_x) q_{ix} + (\mu^x - \lambda^x)(a - c_t) q_{xm}); \end{aligned}$$

for p_{ix},

$$\begin{aligned} T &= t + t (p_{ix} - c_o - a_x) \frac{q_{ix}'}{q_{ix}} - (\mu^m + \mu^{mx}) \frac{(\mu^m + L^{mx})}{(\mu^m + \lambda^{mx})} (a - c_t) q_i \\ &+ \frac{(\mu^m + \lambda^{mx})}{2} (a - c_t) q_j \\ &- \frac{(\mu^m + L^{mx})}{(\mu^m + \lambda^{mx})} (\phi (p_{ix} - c_o - a_x) q_{ix} + (\mu^x - \lambda^x)(a - c_t) q_{xm}), \qquad (25) \end{aligned}$$

and for F_i,

$$\begin{aligned} T &= t - \frac{\mu^m + \lambda^{mx}}{2} (a - c_t) q_j \qquad (26) \\ &- \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}} (\phi (p_{ix} - c_o - a_x) q_{ix} + (a - c_t)(\mu^x - \lambda^x) q_{xm}) \end{aligned}$$

Equating (24) to (26) leads to $p_i^* = c + \frac{a - c_t}{2}$. With $\Phi = \left(\frac{\mu^m + L^{mx}}{\mu^m + \lambda^{mx}} - \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}} \right)$, equating (25) to (26) leads to

$$p_{ix}^* = c_o + a_x - (a - c_t) \frac{\Phi \left[(\mu^m + \mu^{mx}) q_i + (\mu^x - \lambda^x) q_{xm} \right]}{\Phi \phi q_{ix} - t q_{ix}' / q_{ix}}.$$

Now, for $0 < \lambda_* < \lambda^* < 1$, we have both $0 < \frac{1}{\mu^{mx}} \int_{\lambda_*}^{\lambda^*} (\lambda \mu^{mx} - \lambda^{mx})^2 h(\lambda) \, d\lambda = L^{mx} \mu^{mx} - (\lambda^{mx})^2$ and $0 < \int_{\lambda_*}^{\lambda^*} (1 - \lambda)^2 h(\lambda) \, d\lambda = L^{mx} + \mu^{mx} - 2\lambda^{mx}$, from which follows $(\mu^m + L^{mx})(\mu^m + \mu^{mx}) - (\mu^m + \lambda^{mx})^2 > 0$, which is equivalent to $\Phi > 0$.

Solving (26) for the fixed fee yields

$$\begin{aligned} F_i^* &= f + t - \frac{\mu^m + \lambda^{mx}}{\mu^m + \mu^{mx}} \phi (p_{ix} - c_o - a_x) q_{ix} \\ &- (\mu^m + \lambda^{mx})(a - c_t) \left(\frac{q_j}{2} + \frac{\mu^x - \lambda^x}{\mu^m + \mu^{mx}} q_{xm} \right). \end{aligned}$$

Substituting p_{ix} leads to

$$F_i^* = f + t + (\mu^m + \lambda^{mx})(a - c_t)\left(\frac{q_i}{2} - \frac{1}{1 - \Phi\phi q_{ix}^2 / t q_{ix}'}\left[q_i + \frac{\mu^x - \lambda^x}{\mu^m + \mu^{mx}} q_{xm}\right]\right).$$

Finally, after substituting p_i^* and F_i^*, profits simplify to $\pi_i = \frac{\mu^m + \mu^{mx}}{2} t$. ■