Network Growth: Theory and Evidence from the Mobile Telephone Industry

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ABSTRACT

Firms in mobile telephone markets charge one another for delivering calls to subscribers. These so-called termination charges are controversial from a policy perspective since they are fairly high and stable. We present a model of consumer and firm behavior in mobile markets in order to identify the role of termination charges in determining the market equilibrium. We analyze three segments of the mobile market: termination, calling, and subscribing. Our model predicts a "waterbed effect", that is, high termination rates will be associated with low subscription prices, if preferences are the primary source of variation in termination rates. If costs are the main driver of termination rates our model predicts a "tide" hypothesis in which high termination rates exist alongside high subscription prices. We test these and other predictions from our model using international data on mobile subscriptions per person. We find results which are broadly consistent with our model. More specifically, we find evidence that mobile termination rates are positive and significantly related to mobile phone adoption. This result is robust to the inclusion of a variety of other structural, institutional, demographic, and income controls. We also find that competition, internet subscriptions, and a free press are positively associated with mobile phone adoption while fixed termination rates and inequality slow the adoption of mobile technologies.

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*Authors may be contacted by email. Cunningham: bcunning@usna.edu. We obtained our termination market data from Arbinet's voice on thexchange marketplace. Hundreds of Member carriers trade billions of minutes a year on this system. We maintain responsibility for any errors or omissions.

1 Introduction

When consumers contract with firms in network services, they purchase not only access to a firm's network, but also access to the networks with which the firm interconnects. In banking, account holders have free access to an ATM network but consumers and firms face costs whenever an account holder conducts transactions outside their network of ATM machines. Internet service providers will give their subscribers access to a local network which freely connects to the wider internet.

Similarly, in mobile telecommunications a consumer can subscribe to a mobile operator's network. By choosing a particular mobile provider a consumer implicitly reveals the ideal bundle of characteristics which they seek in a mobile phone. Such bundles typically vary in terms of calling options and features, the quality of service, the extent of mobile network coverage, and the type of handset.

A common feature of all mobile phone networks is interconnection. Subscribers to a given network can make and receive calls to and from any other phone worldwide. Typically, mobile phone operators charge other networks when a call is received by its subscribers. This interconnection charge, often referred to as a termination rate, is analogous to the charges which flow across ATM networks when a given bank's account holder conducts an ATM transaction at a competitor's bank.

In telephony, terminating calls is marginally inexpensive, yet firms' termination charges are relatively high and, in many countries, rising. This phenomenon has fueled regulatory concern.[1] Controversies concerning the "correct" termination charge for domestic traffic between long-distance and local telephone companies, competitor and incumbent wireline telephone companies, wireline and wireless firms, and for international traffic, have proved among the most controversial and vexing proceedings before the Federal Communications Commission and the courts.

In these disputes, the relationship between termination rates and subscription plays a key, yet ambiguous, policy role. Regulators, when seeking lower termination charges, claim that low termination rates are efficient, will lead to lower subscription charges, and a greater number of subscribers. For instance, the FCC, pursuant to its

[1]See Armstrong and Sappington (2005) for an outstanding overview of the regulatory issues.

decade-long policy of reducing international settlement rates, stated: [C]onsumers in all countries [will] receive higher quality service, more service options, and lower rates as accounting rates [i.e., termination charges] are reduced to a more cost-based level. Accounting rate reform will also . . . stimulat[e] growth of those services.

However, when seeking to protect high termination charges, regulators take the opposite position and claim that high termination charges are essential to attract investment and stimulate network growth. For instance in the Intercarrier Compensation Further Notice of Proposed Rulemaking, the FCC expressed concern that lower termination rates (intercarrier payments) would lead to less network investment, higher subscription rates, and a lower number of subscribers in rural areas. The FCC stated "Any proposal that would result in significant reductions in intercarrier payments should include a proposal to address the universal service implications. . . many rural LECs collect a significant percentage of their revenue from [termination charges] . . . we must be certain that any reform of compensation mechanisms does not jeopardize the ability of rural consumers to receive service at reasonable rates." Finally, regulators typically fail to consider how their network interconnection policies function within broader cultural, linguistic, social, and political networks important considerations for international calling and developing countries.

Recent economic literature on termination has focused on the efficiency of termination as a means of sharing the costs associated with operating a network, but has largely ignored the importance of termination charges on network subsribership when embedded in other, broader networks. DeGraba (2003) shows that a "bill and keep" system, in which mobile operators do not charge one another for interconnection, can improve the efficiency of mobile networks. Wright (2002) and DeGraba (2002) discuss the extent to which charging for termination helps address differences in willingness to pay and the existence of network externalities. A related literature explores the relationship between termination charges and the returns from adding subscribers to a network. Littlechild (2006) points out that termination charges allow a firm to derive at least three sources of revenue from a subscriber: subscription charges, outbound calling charges, and inbound calling charges. For this reason, a low termination rate might encourage mobile firms to increase the price of either subscriptions or calling charges in order to restore revenues. This so-called "waterbed" effect could lead to fewer mobile subscribers or a lower level of traffic on mobile networks. It is the first of these possibilities that we investigate.

We develop a model of equilibrium behavior in an imperfectly competitive market for mobile telephones. Our model is a three stage process in which (1) consumers choose a subscription offered by one of n mobile differentiated firms while firms simultaneously choose subscription prices (the extensive stage), (2) consumers choose their volume of calls while firms choose the price of calling (the intensive stage), and (3) termination rates are determined by mobile operators. Our model suggests that subscription prices exhibit a waterbed effect; that is, an inverse relationship with termination rates, so long as preferences serve as the primary source of variation in termination rates. Thus, if the elasticity of demand for termination is low, mobile firms will implement a large markup of termination rates over the marginal cost of termination. This increases the profitability of termination per subscriber, so firms lower subscription prices in order to increase profitability. Conversely, if termination rates vary due to differences in the marginal cost of termination, a high termination rate is associated with lower profits from termination, higher subscriber prices, and smaller mobile phone networks.

We test for the existence of the waterbed effect using data from termination markets. We employ a cross-country empirical specification with mobile subscribers per person as the dependent variable and lagged measures of market structure, features of the telecommunications market, linguistic diversity and political freedom proxies, and demographic information as the independent variables. We find that, consistent with our model's predictions, mobile termination rates are a positive and statistically significant factor in determining penetration of mobile phones internationally, while fixed termination rates are negatively and significantly associated with mobile adoption.

We also find statistically significant evidence that mobile phone adoption is increasing in (1) the number of mobile operators in a country (a proxy for the level of competition), (2) the level of internet penetration (a proxy for the level of technological progressivity), (3) greater freedom of the press (loosely, political freedom) and (4) lower levels of income inequality. Importantly, we find that the negative relationship between inequality and mobile phone adoption weakens at higher levels of income per person. This result is consistent with the relatively uniform fixed costs of adopting mobile phones internationally. Our estimates suggest that policy efforts to cap mobile termination may reduce the rate at which mobile phones are adopted internationally. More generally, interconnection fees may encourage the adoption of new communications technologies.

2 Related Literature

The literature regarding access pricing and mobile telephony is relatively well-developed, and we reference a fraction of the contributions. An excellent summary of access pricing is provided by Vogelsang (2003). An outstanding and comprehensive overview of regulatory issues is given in Armstrong and Sappington (2005).

Wright (2004) argues that determination of mobile termination charges is different than standard fixed-line access pricing issues, since in the case of mobile telephony, a firm's customers create the bottleneck. Wright suggests that above cost termination charges make mobile customers more valuable to mobile operators, leading competing firms to lower retail prices in an attempt to capture more customers. Wright observes that a price cap may need to be set in order to lower termination charges. Wright notes that an asymmetric regulatory approach exacerbates the monopoly pricing problem. Wright concludes that if fixed-line firms could negotiate with mobile firms regarding termination charges, and if bargaining power is roughly equal between fixed and cellular firms, the tendency by mobile firms to set high termination rates might be alleviated. Littlechild (2005) suggests that the costs of calling party pays are high, and a transition to receiving party pays would mitigate many of the problems associated with calling party pays. Littlechild also discusses what he calls the waterbed effect, i.e., high termination rates lead to discounting on handsets and calling plans. According to Littlechild, lowering termination rates will reduce the incentive to offer handset discounts. Similarly, Crandall and Sidak (2004) suggest that receiving party pays is the best option for mobile telephony because it aligns the incentives of mobile network operators and mobile customers (i.e., operators are forced to lower costs towards marginal costs). They suggest that if receiving party pays is not adoptd calling party pays, without regulation, is the second-best option, in particular if there is a termination rate negotiation between fixed line and cellular firms. Crandall and Sidak suggest that, given network externalities in mobile telecommunications, the value to callers justifies termination charges greater than marginal cost. Binmore and Harbord (2005) note the conventional wisdom that if fixed-to-mobile rates are unregulated, mobile operators will exploit market power from the termination bottleneck. They construct a bargaining model between fixed and mobile operators that highlights the importance of risk aversion and impatience in the determination of relative bargaining power. In particular, they note that if the new (mobile) entrant is more impatient or has a higher cost of capital, the established (fixed line) firm can bargain down termination rates. However, if the entrant knows that the government will quickly intervene in negotiations to set rates, the entrant will end up setting higher termination rates.

Birke and Swann (2005) provide an empirical analysis of mobile phone system choice in UK and find that "pure" network effects (on-net calls) dominate "indirect" network effects (off-net calls) even if there is no price differential for the calls. They conjecture that some users (e.g., family) matter more to mobile users, and that household effects are strong. Birke and Swann suggest that the high price of off-net calls can not only be a result of market power, but can be a significant source of market power, which can be used to preempt entry by new competitors (i.e.,. high switching costs). Finally, they note that the standard assumption that network effects grow linearly is not supported by the evidence. Barnett and Kaserman (1998) argue that regardless of the specific policy mechanism to increase the size of a network, it is likely that any subsidy scheme will reduce rather than increase social welfare, since, even if network externalities exist, at high enough penetration rates there may be vanishingly small marginal external benefits to additional subscribers. Importantly, when network externalities are instead infra-marginal, unsubsidized market-determined prices yield the optimum. Moreover, a uniform subsidy in the presence of non-uniform externalities will not produce a Pareto optimum. Barnett and Kaserman note that the potential value of a subsidy needs to be weighed against the welfare loss of collecting funds for the subsidy.

3 Equilibrium Determinants of Network Size

In order to contribute to the existing literature we offer a model of the termination, calling, and subscription markets. Begin by assuming that termination fees, the price of calling, and the price of subscribing are determined as part of a three-stage process.[2] Throughout the model we allow for an arbitrary number of firms.

In the first stage, consumers choose to subscribe to the services of one mobile firm and firms choose the price of subscriptions. We refer to this sub-game as the extensive segment of the market for mobile services. We assume firms are horizontally differentiated in the market for subscriptions and that consumers buy subscriptions from firms based upon a number of criteria, including the price of calling and their preferences for the unique features offered by a mobile firm.

In the second stage, consumers choose the amount of time they spend calling and mobile operators set the price per minute of calling. This is the intensive segment of the mobile market. We assume that firms act as monopolists in pricing the minutes of calling once consumers have committed to a subscription. In the final stage of the game we assume that mobile firms act as monopolists in setting termination rates.

3.1 Termination Rates

To find the equilibrium for each segment of the mobile market we use backward induction. Our model of the termination segment assumes that the number of inbound minutes received by the average consumer on a mobile network is decreasing in the termination rate set by a particular mobile operator and that the demand for termination has a constant price elasticity.[3] If $\tilde{m}$ is used to denote the average num-

[2] We assume a calling party pays (CPP) regime (i.e., when a firm originates a call it must make a payment to the receiving firm in exchange for the termination service).

[3] In our subsequent analysis of the intensive stage we show that profit-maximizing network operators will increase the per-minute price of calling in order to pass along an increase in the marginal

ber of minutes a network subscriber receives, and t_c is the termination fee for calls, we assume that $\tilde{m} = t_c^{-\gamma}$ where γ is the price elasticity of demand for terminating services.[4]

We assume that the marginal cost of terminating a call is constant and use c_t to denote the marginal cost of termination.[5] Under these assumptions, termination profits from a single subscriber are:

$$\pi_t = t_c\tilde{m} - c_t\tilde{m} \tag{1}$$

We assume that firms set termination rates to maximize these profits.

Proposition 3.1. *Equilibrium termination rates are a constant markup over the marginal cost of terminating calls. Termination rates increase with the marginal cost of termination and decrease in the elasticity of demand for termination services. Equilibrium termination profits per subscriber decrease with both the marginal cost of termination and the elasticity of demand for termination.*

Proof. After substituting the expression for termination service demand into (1) we find the following first-order condition for termination:

$$\gamma c_t t_c^{-\gamma-1} - (\gamma - 1)t_c^{-\gamma} = 0. \tag{2}$$

The first term in this condition is the marginal benefit from termination. Termination rates reduce costs on the margin since a higher termination rate leads to fewer inbound minutes on a network. The cost of higher termination rates comes in the form of lower termination revenues as the volume of calls decreases. This marginal

cost of placing calls. Part of the marginal cost of placing calls is the termination rate. For this reason an increase in termination rates will ultimately lead to higher calling prices and a smaller volume of calling minutes.

[4] In order to ensure the existence of an interior solution for the maximization of termination profits, we make the additional assumption that $\gamma > 1$.

[5] Note that we obtain similar predictions regarding the termination segment if we use a linear demand curve for termination services, set the marginal cost of termination to zero, and assume that mobile operators maximize total revenues.

cost is reflected in the second term in (2). Solving for the profit-maximizing termination rate, we obtain:

$$t_c^* = \frac{\gamma}{\gamma - 1} c_t. \tag{3}$$

This result supports the first claim in the proposition. Firms set a simple markup of termination rates over the marginal cost of termination services in order to maximize profits. The markup is a function of the elasticity of termination demand.

By substituting this expression into the termination demand function and the profit function we find that the equilibrium volume of inbound minutes for the average subscriber and equilibrium profits from termination are, respectively:

$$\tilde{m}^* = \frac{(\gamma - 1)^{\gamma}}{\gamma^{\gamma} c_t^{\gamma}} \tag{4}$$

$$\pi_t^* = \frac{(\gamma - 1)^{\gamma - 1}}{\gamma^{\gamma} c_t^{\gamma - 1}} \tag{5}$$

Because we assume $\gamma > 1$, the results in (4) and (5) indicate that a higher marginal cost of termination will lead to higher termination rates and lower termination profits per subscriber.

It is straightforward to show that termination rates are decreasing in the elasticity of demand. Moreover, note that the derivative of profits with respect to the elasticity of demand is:

$$\frac{\partial \pi_t^*}{\partial \gamma} = \frac{(\gamma - 1)^{\gamma - 1}}{\gamma^{\gamma}} c_t^{1-\gamma} \left[\ln(\gamma - 1) - \ln \gamma - \ln c_t\right] < 0. \tag{6}$$

Thus, a higher elasticity of demand decreases the markup of termination rates above marginal costs, thereby reducing the profitability of termination. □

The key insight from Proposition 3.1 is that termination rates and the per-consumer profitability of termination need not vary positively. In our model, termination rates can vary across markets for two reasons: technology and preferences. According to Proposition 3.1, if technology is the primary source of variation in termination rates, we can expect termination rates and the profitability from termination to move inversely since a higher termination rate is a signal of a significant marginal cost from offering termination services. On the other hand, if preferences are the primary source of variation in termination rates we would expect to see higher termination rates associated with large termination profits per subscriber. As we will show in subsequent analysis, the ultimate relationship between termination rates and the size of mobile networks depends upon the source of variation in termination rates.

3.2 The Price of Calling

Turning to the second stage, we assume that a consumer's utility from calling is determined by:

$$U_c = \frac{\eta}{\eta - 1} \int_0^k m(i)^{1-1/\eta} di - p \int_0^k m(i) di \tag{7}$$

where $\eta > 1$, p is the per-minute price of calling, $m(i)$ is the number of minutes a consumer spends calling individual i, and k is the mass of individuals who (1) have access to a phone and (2) the consumer would like to contact.[6]

To find the demand function for calls from one individual to another, we solve the first-order condition for maximization of U_c with respect to minutes of calling. We derive a straightforward demand function for call minutes, $m(i, p) = p^{-\eta}$; thus, demand for minutes exhibits a constant price elasticity.[7] This result can be combined with the expression for utility from calling in order to obtain the indirect utility function for calling:

$$U_c = \frac{1}{\eta - 1} k p^{1-\eta}. \tag{8}$$

Clearly, a consumer's utility from calling is decreasing in the price of minutes and increasing in the number of contacts (i.e., the parameter k).

We now turn to the firm's decision regarding the price of minutes and a firm's costs associated with calling activity. To begin, we assume that, for each subscriber, a constant fraction of all calls, α, are placed to mobile phones while the remaining

[6] Although we allow for the possibility that a subscriber might contact people on different phone networks (i. e. fixed and mobile), we assume there is one price charged to the subscriber for any outbound call.

[7] Clearly, $m(i) = 0$ if individual i does not have access to a phone or is not in the interval $[1 \ldots k]$.

fraction, $1-\alpha$, are placed to fixed phones. We further assume that a fraction, β, of mobile to mobile calls are terminated with a competitor's subscriber.

Finally, we assume that there are three types of marginal costs associated with originating calls. The first is an internal cost per minute of conveying calls, denoted by c_0. The second is the termination fee that the firm terminating a call charges the firm originating the call: t_c. The third is the termination fee paid for calls which terminate with fixed-line firms: t_f. We denote the total marginal cost, which is a weighted sum of the individual marginal costs, by $c = c_0 + \alpha\beta t_c + (1-\alpha)t_f$.[8]

If we let $M = \int_i m(i,p)di$ represent the total originating minutes from one subscriber we can conclude that the profit from calling activity by one subscriber (the intensive profit) net of termination costs is:

$$\begin{aligned} \pi_c &= pM - c_0 M - t_c\alpha\beta M - t_f(1-\alpha)M \\ &= p\int_0^k m(i,p)di - c\int_0^k m(i,)di \\ &= kp^{1-\eta} - kcp^{-\eta} \end{aligned} \tag{9}$$

where the third equality comes from substituting the demand for minutes into the intensive profit function.

Proposition 3.2. *In equilibrium the price of a minute of calling is a constant markup over the total marginal cost of originating a call. Consumer utility from calling and a firm's profits from the calling activity of a single subscriber are both decreasing in the total marginal cost of originating calls.*

Proof. Solving the first-order condition for maximization of termination profits with respect to the price of calling yields the equilibrium price of a minute of calling:

$$p^* = \frac{\eta}{\eta - 1}c. \tag{10}$$

[8] It is important to note that these assumptions will rule out the possibility that mobile firms will price subscriptions in order to increase their on-network traffic (that is, reduce β) and thereby reduce the total marginal cost of originating calls. These strategic considerations are beyond the scope of the current paper.

It is clear from this expression that the price of a minute of calling is a markup over the marginal cost of originating a call, where the markup is a function of η. The equilibrium utility a consumer receives from calling, along with the profits from calling, can be obtained by substituting the expression for equilibrium call pricing into the consumer's utility function (8), U_c, and the profit function (9), π_c:

$$U_c^* = \frac{k}{\eta^{\eta-1}(\eta-1)^{2-\eta}c^{\eta-1}} \tag{11}$$

$$\pi_c^* = \frac{k(\eta-1)^{\eta-1}}{\eta^{\eta}c^{\eta-1}}. \tag{12}$$

Since we assume that $\eta > 1$ we can conclude that both of these expressions are decreasing in the total marginal cost. $\square$

In our model, firms act as monopolists in the calling and termination markets. Thus, it is intuitively plausible that we find markup behavior in both markets. Our results also suggest that a mobile network will generate lower utility for its subscribers and lower profits for its operator if the network exhibits a high marginal cost for originating minutes.

3.3 Network Size

We assume there are n mobile operators equally spaced on a unit circle (as in Salop's model of differentiated goods). There are L consumers at each point on the circle. We assume the consumer located at point y^* on the circle obtains utility:

$$U = U_c^* - \delta\,|y - y^*| - p_s \tag{13}$$

when the consumer subscribes to a mobile operator located at point y on the circle. The variable p_s is the price charged by the operator located at this point while U_c^* is the consumer's utility function for calling evaluated at the calling price set by this operator. As a consumer moves further away from his or her ideal type of mobile network, utility decreases at a constant marginal rate of δ.

If a mobile operator's neighbor on the circle charges a subscription price of $\overline{p}_s$ and prices minutes such that consumers on the network experience utility of $\overline{U}_c^*$ then a consumer at a distance of x from the operator will be indifferent between a mobile operator and its neighbor if:

$$U_c^* - \delta x - p_s = \overline{U}_c^* - \delta(1/n - x) - \overline{p}_s. \tag{14}$$

Solving (14) for x we obtain the distance of the indifferent consumer from the mobile operator:

$$\hat{x} = \frac{1}{2\delta}\left(U_c^* - \overline{U}_c^* + \overline{p}_s - p_s + \frac{\delta}{n}\right) \tag{15}$$

while the number of subscribers for a particular mobile operator is:

$$N(p_s) = \int_{-\hat{x}}^{\hat{x}} L dx = \frac{L}{\delta}\left(U_c^* - \overline{U}_c^* + \overline{p}_s - p_s + \frac{\delta}{n}\right). \tag{16}$$

A firm will have a larger network if (1) it has a lower marginal cost for originating calls, so that consumers experience lower call prices and higher utility from joining the network, (2) its neighbors have a higher marginal cost for originating calls, (3) it sets a lower subscription price, (4) neighbors charge a higher subscription price, and (5) the number of other operators is small.

A mobile operator's total profits from subscriptions, originating calls, and termination are:

$$\Pi = (p_s + \pi_c^* + \pi_t^*)N(p_s) - c_s N(p_s). \tag{17}$$

Proposition 3.3. *Subscription prices are strategic complements and decrease in the per-subscriber profit from calling and termination. The number of subscribers on a single firm's network is increasing in the per-subscriber profit from calling and termination.*

Proof. Solving the first-order condition for maximization of total profits with respect to the subscription price yields a mobile operator's best-response functions for subscription pricing and network size:

$$\tilde{p}_s = .5\left[U_c^* - \overline{U}_c^* + \overline{p}_s + \frac{\delta}{n} + c_s - (\pi_c^* + \pi_t^*)\right] \tag{18}$$

$$\tilde{N} = \frac{.5L}{\delta}\left[U_c^* - \overline{U}_c^* + \overline{p}_s + \frac{\delta}{n} + \pi_c^* + \pi_t^* - c_s\right]. \tag{19}$$

According to (18), if a firm's nearest competitor increases its subscription price ($\overline{p}_s$) the best response is to increase its own subscription price ($\tilde{p}_s$). It is also clear that per-subscriber termination and calling profits serve to reduce subscription prices and increase the number of subscribers. □

The subscription price best response function suggests that for a one unit increase in a competitor's price, a given firm will increase it's own price by one-half. A competitor's subscription price increase will lead to an increase in a firm's subscriber base even after these price increases are optimally matched. The model also predicts that a mobile operator will set lower prices and seek a larger network of subscribers when the marginal cost of adding a subscriber is low.

We find a "waterbed effect," wherein lower subscription prices are associated with higher termination rates, provided higher termination rates are driven by a low elasticity of demand for termination. As described in Proposition 3.1, if higher termination rates emerge as a consequence of larger markups over the marginal cost of termination (i. e., the elasticity of demand is low) the profit per subscriber from termination is large. In this situation, mobile operators reduce their subscription prices and pursue a larger network in order to capture greater profits. On the other hand, if higher termination rates emerge as a consequence of a high marginal cost of terminating, profits from termination are low and operators increase the price of subscribing in order to restore overall profitability.

Fixed termination rates increase the marginal cost of originating calls. This has two effects. First, the per-minute price for calling is greater, since fixed termination rates are marked-up and passed through mobile firms, thereby reducing a consumer's utility from calling (U_c^* falls). Second, the profits from calling are lower (π_c^* falls). Both of these effects suggest that fixed termination rates will unambiguously display a negative relationship with mobile network size.

We now focus on the symmetric equilibrium for subscription pricing so that each mobile firm charges the same price: $\tilde{p}_s = \overline{p}_s = p_s^*$.[9] Using the best-response function for pricing of minutes, we find that the symmetric equilibrium price of subscribing is:

$$p_s^* = \frac{\delta}{n} + c_s - (\pi_c^* + \pi_t^*). \tag{20}$$

Note that the subscription prices under the symmetric equilibrium can be negative if the profits from calling and/or terminating are large enough. In this sense, the profits per subscriber for calling/termination act as an implicit subsidy which reduce a consumer's cost for subscribing to a mobile service. It is important to note that this subsidy may manifest in subtle ways, including below-market pricing of hardware.

We let U_0 represent a consumer's total utility from not subscribing to any mobile operator's service and assume that this value is the same for all consumers. Under the symmetric equilibrium price the consumer who is indifferent between two neighboring operators has utility of $U_c^* - \delta\hat{x} - p_s^*$. We assume that $U_c^* - \delta/2n - p_s^* < U_0 < U_c^* - p_s^*$. The first inequality guarantees that there is a mass of consumers who choose not to subscribe to any mobile service under the symmetric equilibrium (in other words, the consumer who is indifferent between two neighboring operators is so far away from a given operator that s/he chooses not to subscribe). The second inequality ensures that there are a strictly positive number of mobile subscribers for each operator. These assumptions jointly ensure that our equilibrium is one in which some consumers subscribe to mobile services, but the market is not completely covered. Since mobile phone services are relatively new, we believe this is the most relevant equilibrium.

At the symmetric equilibrium price, a consumer who is indifferent between subscribing and not subscribing lies at a distance of:

$$x^* = \frac{1}{\delta}\left(U_c^* - U_0 - p_s^*\right) \tag{21}$$

[9] In order for the symmetric equilibrium to exist we must further assume that (1) each operator faces the same marginal cost for originating minutes, so that $U_c^* - \overline{U}_c^* = 0$ and (2) the marginal cost of adding a mobile subscriber is the same for all mobile operators.

from a given firm.

Proposition 3.4. *The market-wide mass of consumers subscribing to mobile services is increasing in the number of mobile operators and per-subscriber profits from calling and termination. The number of subscribers decreases with the total marginal cost of originating calls, the marginal cost of adding a subscriber to a network, and the utility from the outside option.*

Proof. Since we are analyzing a symmetric equilibrium, the equilibrium mass of consumers subscribing to all mobile networks ($\aleph^*$) is the product of the number of subscribers for a single firm and the number of firms in the market. Thus:

$$\aleph^* = nN^* = n\int_{-x^*}^{x^*} Ldx = \frac{nL}{\delta}\left(U_c^* - U_0 - \frac{\delta}{n} - c_s + \pi_c^* + \pi_t^*\right) \tag{22}$$

The total marginal cost of originating calls decreases U_c^* (holding constant the per-subscriber termination/calling profits), thereby decreasing the total number of subscribers. The proof of the remaining claims in the proposition are obvious. $\square$

In our model, the number of firms increases the size of networks for two reasons. First, a larger number of firms implies more intense competition for subscribers, leading to lower subscription prices and a larger number of subscribers for each firm. Since we use a symmetric equilibrium concept, this increase in per firm subscribers arises for each firm, leading to a larger overall number of subscriptions. Second, Proposition 3.3 established that a single firm's best response to higher per-subscriber termination/calling profits is lower subscriber prices and hence a larger subscriber base. Since $\partial\aleph^*/\partial\pi_i^* = 2n\,\partial\tilde{N}/\partial\pi_i^*$, the equilibrium market-wide impact of calling/termination profits on the number of subscribers, on the margin, is twice the sum of the individual firm-level impacts. This result emerges as a consequence of strategic complementarity in subscription prices: each firm responds to falling competitor prices but cutting its own price, which puts further downward pressure on subscriber prices. More generally, our model's predictions regarding the equilibrium determinants of network size provide the foundation and motivation for subsequent empirical analysis.

4 Hypotheses and Empirical Evidence

Our theory suggests a number of factors which influence the equilibrium number of mobile phone subscribers. We are particularly interested in the relationship between termination and subscription markets. We suggest that termination profits per subscriber are a key determinant of subscriptions. However, measures of disaggregated profits for mobile firms are not available. Thus, we use per-minute termination rates as a measure of outcomes in the termination market. Our model yields three hypotheses regarding termination rates.

4.1 Termination Rates and Subscription Prices

The "waterbed" hypothesis suggests termination rates are negatively related to subscription prices and positively related to total network size across mobile markets. Two conditions must hold for this hypothesis to emerge from our model: (1) variation in termination rates across markets must be driven by differences in elasticities of demand for termination services (γ) and (2) a small fraction of all originating calls are mobile-to-mobile and terminate on a competitor's network ($\alpha\beta$ is small). That both conditions lead to the hypothesis can be seen by considering the role of preferences in determining equilibrium network size:

$$\begin{aligned}
\operatorname{sign}\frac{\partial \aleph^*}{\partial \gamma} &= \operatorname{sign}\left[\left(\frac{\partial U_c^*}{\partial c^*}+\frac{\partial \pi_c^*}{\partial c^*}\right)\frac{\partial c^*}{\partial t_c^*}\frac{\partial t_c^*}{\partial \gamma}+\frac{\partial \pi_t^*}{\partial \gamma}\right] \\
&= \operatorname{sign}\left[\alpha\beta\underbrace{\left(\frac{\partial U_c^*}{\partial c^*}+\frac{\partial \pi_c^*}{\partial c^*}\right)\frac{\partial t_c^*}{\partial \gamma}}_{\text{positive}}+\underbrace{\frac{\partial \pi_t^*}{\partial \gamma}}_{\text{negative}}\right].
\end{aligned}$$

If $\alpha\beta$ is sufficiently small, the sign of $\partial\aleph^*/\partial\gamma$ is negative. As shown in (6), $\partial t_c^*/\partial\gamma$ is negative. In markets with a low elasticity of demand for termination services, termination rates and termination profits per subscriber are high, leading to larger mobile subscriber bases while the converse holds in markets with a high elasticity of demand for termination.

An alternative implication of our model is the "tide" hypothesis suggests that termination rates are positively related to subscription prices and negatively related to network size across markets. This hypothesis will hold under two circumstances. First, if mobile-to-mobile calls terminating on competitor networks are a large share of all originating calls ($\alpha\beta$ is large) we can conclude that $\partial\aleph^*\partial\gamma > 0$. In this situation, markets with a low elasticity of demand for termination services will exhibit high termination rates and small networks. An inverse relationship between termination rates and network size will also arise if the marginal cost of termination services is the primary source of cross-market variation in termination rates. The results from our model above indicate that in a market with a high marginal cost of termination, termination rates are large, profit from termination is low, the price of calling is high, consumer utility and firm profit from calling is low, the price of subscribing is high, and mobile subscribers are small in number.

Finally, the "countervailing effects" hypothesis suggests that termination rates are unrelated to network size. This hypothesis emerges whenever the market-expanding "waterbed" effect caused by preferences under the first hypothesis offsets the market-shrinking "tide" effect generated by either preferences or the technology underlying termination.

4.2 Specification

To test these hypotheses we use a reduced-form specification based upon the expression for the equilibrium number of subscribers in a mobile market (equation (23)). For empirical purposes we identify a market as a country. In order to avoid scaling issues we use number of mobile subscriptions per capita as our dependent variable. We assume that actual mobile subscribers per capita in country i ($\tilde{\aleph}_i$) deviates by a white-noise random error term (ε_i) from the theoretically-implied ratio of the mass of subscribers to the overall mass of consumers: $\tilde{\aleph}_i = \aleph_i^*/L_i + \varepsilon_i$. Our model suggests that there are four categories of factors which might influence the equilibrium ratio of subscriptions to the mass of consumers. The sources for our data on these factors are given in the Appendix while summary statistics for all of the variables are presented in Table 1.

The first category of variables in our specification measure market structure. Our model predicts that mobile subscriptions depends upon the number of mobile operators (n) or the availability of communication options which increase consumer utility in the absence of a mobile subscription (U_0). We group these structural variables into a column vector σ_i. The second group of factors capture the cost of termination and we group these costs in a column vector $\tau_i = [t_{c,i}, t_{f,i}]'$. Our model predicts a relationship between termination rates, the profits from originating and terminating calls (π_c^* and π_t^*) and the equilibrium size of networks, $\aleph_i^*$. We also include a vector of demographic and institutional controls, Δ_i, in order to estimate the possible impact of preferences on network size. These factors might shift the utility which consumers experience from using a mobile phone to make calls (U_c*). Finally, we include a vector of income controls, ψ_i.

We use a linear specification which relates the four categories of explanatory variables to the number of mobile phone subscribers per capita:

$$\tilde{\aleph}_i = \beta_0 + \beta_\sigma' \sigma_i + \beta_\tau' \tau i + \beta_\Delta' \delta_i + \beta_\psi' \psi_i + \varepsilon_i. \tag{23}$$

We use Ordinary Least Squares to estimate the coefficient vectors β_j. In order to achieve identification we measure the independent variables with a time lag, whenever possible. This should reduce the possibility that present values of the error term are correlated with the explanatory variables.

4.3 Empirical Results

We include four structural variables in the vector σ. The first is a dummy variable taking on the value of one when cellular markets operate under a "receiving party pays" (RPP). In RPP markets, such as the United States, callers pay to place calls and they also pay when they receive calls on their cellular phones. Some have theorized that in RPP countries, callers are likely to switch off their phones, or generally use their phones less, since calling activity is more costly. This behavior would reduce the value of subscribing to a cellular service and we would anticipate a negative coefficient on the RPP dummy variable. Our second structural variable is the number of mobile operators. This variable enters directly into our model's equation for the equilibrium size of networks and has a positive impact on $\aleph^*$. As the number of mobile operators increases, the mobile market becomes more competitive and prices (both calling and subscription) should fall. This will increase the size of mobile networks. We also include the average share of mobile networks which are owned by the state.[10] Our model is derived under the assumption of profit-maximizing behavior by mobile operators. State ownership would likely push firms away from profit-maximizing behavior and we include controls for state ownership to control for this possibility. Our final structural variable is the number of internet subscription per person. This variable can capture a number of facets of the telecommunications market in any given country. First, the internet may be an important communications rival to cellular phone and consumers may substitute internet access for mobile subscription. Alternatively, a high level of internet penetration may proxy for a telecommunications policy environment which generally encourages the adoption of new technologies, including mobile phones. For these reasons the coefficient on internet penetration could be positive or negative.

Our first estimates of the specification (23) include only the four structural measures. Results from this estimation are in the first column of Table 2. The coefficients are broadly consistent with our theory. In particular, government ownership is negatively and significantly associated with mobile subscriptions per person. This result suggests that government ownership may slow the adoption of mobile technologies. In addition, internet penetration is positively and significantly associated with mobile subscriptions per person. We find that rapid adoption of one new communications technology is positively associated with the adoption of others and don't find evidence in support of substitution between mobile and internet subscriptions. The coefficients on the RPP dummy and the number of mobile operators are positive and negative, respectively. While these point estimates are consistent with theory they

[10]This average is computed across firms and is unweighted. For example, if there are two firms in the market one completely state owned and one with no state ownership, our government ownership share would be .5.

are not statistically significant.

We now turn to the role of termination markets in determining the size of mobile networks. Recall that there are two termination rates in our specification: fixed and mobile. Our model predicts that fixed termination rates will reduce profits in mobile markets by increasing the marginal cost of calls. Further, mobile operators will pass along high fixed termination rates to consumers which decreases the number of consumers subscribing to mobile services. In contrast, mobile termination rates will vary positively, negatively, or insignificantly with network size if the conditions underlying the waterbed, tide, or countervailing effects hypothesis hold true, respectively. In the second column of Table 2 we add termination rates to the prior specification. We also include the interaction of mobile termination rates with the number of mobile operators in our specification. In a more competitive environment, termination profits may be lower so that the termination market may be less important in determining the number of subscribers.

The coefficient estimates on termination rates are consistent with our model's predictions. Fixed termination rates obtain a negative and significant coefficient. In addition, mobile termination rates are positive and significantly related to the number of mobile subscriptions per person suggesting that the waterbed effect is dominant in our sample. Higher termination rates are positively associated with adoption of mobile phones. Further, we obtain a negative and significant coefficient on the interaction between mobile termination rates and the number of mobile operators. This result suggests that mobile termination rates are a weaker predictor of mobile phone subscriptions in more competitive environments. Turning to our structural measures, once termination rates are included in our specification government ownership of mobile firms is no longer a significant predictor of subscriptions. Internet subscriptions maintains the same sign and significance in our specification. Interestingly, the number of mobile firms is now positive and significant suggesting that competition directly encourages larger numbers of consumers to subscribe to mobile services, implying that competition is not an impediment to network growth. This result is also consistent with our model's predictions.

In the third column of Table 2 we add a group of institutional and demographic characteristics. We include population density in order to control for the possibility that demand for communication technology may vary with the proximity of individuals. On one hand, a dense population may be more urbanized and industrialized, which could lead to greater demand for mobile phones. Alternatively, a dense population may have access to other means of communication. We include the average age of the population since younger consumers may have a greater proclivity to adopt new technologies. Our model predicts that when consumers have a smaller number of individuals they would like to contact (k is lower) they experience lower utility from calling activity and are less likely to subscriber to mobile services. We include an index of linguistic fractionalization as a proxy for barriers to communication. Finally, general government repression of communication may lead to institutional barriers to mobile phone adoption. We include an index of government repression of the press as a control for this possibility.

We obtain theoretically-plausible coefficient estimates on all of these variables. Population density varies positively with mobile phone adoption while linguistic fractionalization, press repression, and the average age of the population vary negatively with mobile phone adoption. However, none of these coefficients are statistically significant. Our coefficient estimates on termination rates maintain their sign and significance when the demographic and institutional controls are added to the specification, although the interaction between the number of mobile operators and mobile termination rates is no longer significant. None of the coefficient estimates on the structural variables are statistically significant in the third column.

In the fourth column of Table 2 we add real GDP per capita to the specification in order to estimate the impact of income on mobile phone adoption. The positive and significant coefficient on this variable suggests that mobile phones are a normal good and subscriptions are higher in more affluent markets. Interestingly, press repression has a significant negative coefficient once we control for income, suggesting that government interference in communication between the press and the public may also involve interference with other forms of communication. Prior results continue to hold; most notably the number of mobile operators is significant in this specification.

Our income coefficient estimates may be sensitive to including additional controls in the specification. More specifically, there is reason to believe that the distribution of income may directly and indirectly effect the rate of mobile phone adoption. In a market with a highly unequal distribution of income, there is a potential for a large number of low-income consumers who will decide not to adopt mobile phones. Moreover, since an increase in income per person can, potentially, shift the entire distribution of consumers upward we might expect that income will reduce the role of inequality in determining mobile phone adoption. We test for this possibility by including the interaction of inequality with income per capita in our specification. We add the distributional variables to our specification in the fifth column of Table 2. The coefficient on income inequality is negative and significant suggesting that inequality reduces mobile subscriptions. The income-inequality interaction term obtains a positive and significant coefficient suggesting that inequality matters less in mobile markets with high average income. Interestingly, there is no significant positive income effect in our final specification. This specification also suggests that termination rates, competition, and internet adoption are positive and significantly related to mobile phone adoption. Further, fixed termination rates, income inequality, and press repression significantly slow the adoption of mobile phones. Income per capita can also indirectly increase adoption by weakening the connection between inequality and mobile phone subscriptions.

5 Conclusion

We have presented a model of consumer and firm behavior in mobile markets. Our model predicts equilibria in three segments of the market for mobile phones: termination, calling, and subscription. We predict that mobile termination rates will increase the number of consumers who subscribe to mobile services provided that preferences are the primary source of variation in termination rates across markets. If, however, costs drive mobile termination rates they will lower the number of mobile subscribers. We test these and other predictions from our model using international data on mobile subscriptions and obtain results which are broadly consistent with our model. More precisely, we find evidence that mobile termination rates are positive and significantly related to mobile phone adoption. This result is robust to the inclusion of a variety of structural, institutional, demographic, and income controls.

Our results suggest that policies designed to limit or cap termination rates may slow the rate of adoption of mobile phones. These results are potentially relevant to other telecommunications markets. Internet service providers (ISPs) are currently investigating the possibility of charging for the delivery of traffic to subscribers. Such charges are roughly analogous to termination rates. Certain advocates of "network neutrality" have suggested that ISPs should be prohibited from charging for delivery of traffic. Our model and empirical results suggest that certain network neutrality principles could lead to slower adoption of high-speed internet connections and higher internet subscription prices.

Future work could formally analyze the applicability of our model to other telecommunications markets. In addition, the welfare consequences of termination rates are worthy of exploration.

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6 Appendix

Data Sources

Company data (platform, launch year, etc.): Telegeography "Global Comms Database" at `http://www.telegeography.com/ee/global_comms/search_company_wireless_nets.php` (by subscription). Those data reflect the figures in the Global Comms Database as of September 1, 2006.

2005 Ownership Data: Telegeography "Global Comms Database" at `http://www.telegeography.com/ee/global_comms/search_company_wireless_nets.php` (by subscription). Those data reflect the figures in the Global Comms Database as of September 1, 2006.

2003 Ownership Data: To determine whether 2005 ownership data differred from 2003 ownership data, the Lexis "Mergers and Acquistions Reports-Company Reports" databas3 (file name is "ALLMA" and the hierarchy is "Area of Law- By topic/Entertainment/Due Dilligence/Company and Financial Information Company and Financial/Mergers and Acquisitions.) Searches were done for each company (as well as alternative company names provided by Telegeography) to determine any ownership change between January 1, 2003 to December 31, 2005. In addition, companies websites were consulted to verify data.

> Variable Definitions: mob04 - number of mobile subscriptions per thousand people in 2004, rpp03 - dummy variable equal to one in receiving party pays countries. num_mob_ops_03 - the number of mobile operators in 2003. i_term_mob_nops03 - interaction between the number of mobile operators and the termination rate. govt_own0304 - government ownership in 2003 or 2004 if 2003 data unavailable. internet03 - number of internet subscriptions per thousand people in 2003. term_prop03 - fixed termination rate in 2003. term_mob_all03 - mobile termination rate in 2003. popdens03 - population density in 2003. ave_age03 - average age of the population in 2003. language_frac01 - linguistic fracitionalization, 2003. rgdpch00 - real GDP in 2000, determined by PPP. giniun00 - Gini coefficient in 2000. irgdp_gini00 - interaction between Gini coefficient and real GDP in 2000.

Table 1: Summary statistics

Variable	**Mean**	**Std. Dev.**	**N**
mob04	41.707	35.751	85
rpp03	0.047	0.213	85
num_mob_ops_03	3.2	1.37	85
i_term_mob_nops03	0.404	0.189	85
govt_own0304	0.223	0.206	85
internet03	16.683	18.521	85
term_prop03	0.079	0.059	85
term_mob_all03	0.131	0.048	85
popdens03	114.981	143.545	85
ave_age03	54.159	152.638	85
language_frac01	0.366	0.293	85
pressfree03	20.518	18.809	85
rgdpch00	8406.748	8001.236	85
giniun00	38.919	9.170	85
irgdp_gini00	294624.187	250103.975	85

Table 2: Dependent Variable: Mobile Subscriptions Per Person

	(1)	(2)	(3)	(4)	(5)	(6)
cons	17.367	13.854	16.049	16.049	14.722	47.030
	(4.527)***	(5.865)**	(9.622)*	(9.622)*	(8.540)*	(18.031)***
rpp03	-5.504	5.910	4.050	4.050	6.322	7.891
	(7.459)	(4.775)	(4.679)	(4.679)	(4.664)	(5.591)
num-mob-ops-03	.191	3.624	3.493	3.493	4.549	4.329
	(1.052)	(1.909)*	(2.389)	(2.389)	(2.259)**	(2.542)*
govt-own0304	-11.808	-6.791	-7.472	-7.472	-5.023	-7.338
	(5.639)**	(6.413)	(7.552)	(7.552)	(7.090)	(8.693)
internet03	1.558	1.360	1.390	1.390	.742	.798
	(.094)***	(.133)***	(.168)***	(.168)***	(.223)***	(.221)***
term-prop03	.	-136.140	-102.239	-102.239	-150.776	-187.515
		(49.022)***	(56.496)*	(56.496)*	(57.607)***	(59.379)***
term-mob-all03	.	146.026	157.388	157.388	177.339	195.284
		(59.464)**	(85.757)*	(85.757)*	(83.185)**	(98.069)**
i-term-mob-nops03	.	-30.649	-31.028	-31.028	-29.972	-31.802
		(15.426)**	(18.936)	(18.936)	(20.639)	(24.665)
popdens03	.	.	.001	.001	-.003	-.006
			(.002)	(.002)	(.009)	(.011)
ave-age03	.	.	-.018	-.018	-.005	-.007
			(.013)	(.013)	(.008)	(.009)
language-frac01	.	.	-8.316	-8.316	-7.518	-7.411
			(5.878)	(5.878)	(5.869)	(6.179)
pressfree03	.	.	-.096	-.096	-.203	-.232
			(.085)	(.085)	(.090)**	(.117)**
rgdpch00	.	.	.	.	.001	-.001
					(.0005)**	(.001)
giniun00	.	.	.	.	.	-.691
						(.249)***
irgdp-gini00	.	.	.	.	.	.00005
						(.00003)*
N	131	121	108	108	93	85
R^2	.732	.782	.794	.794	.833	.852
F	79.325	61.99	39.653	39.653	40.246	37.351