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THE EFFECT OF ENTRY AND MARKET STRUCTURE ON CELLULAR PRICING TACTICS*

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Abstract

We test the effect of entry on the tariff choices of incumbent cellular firms. We relate the change in the breadth of calling plans between 1996, when incumbents enjoyed a duopoly market, and 1998, when incumbents faced increased competition from personal communications services (PCS) firms. Entry by PCS competitors differed across geographic markets due to the number of licenses left undeveloped as a result of the bankruptcy of some of the auctions' winning bidders and due to variation across markets in the time required to build a sufficiently large network of wireless infrastructure. We find that incumbents increase tariff variety in markets with more entrants and that this effect is not explained by demographic heterogeneity or cost differences in maintaining calling plans across markets. We also find that incumbents are more likely to upgrade their technology from the old analog technology to the new digital technology in markets with more entry, suggesting that entry also has indirect effects on tariff choice via firms' technology adoption decisions.

Keywords: entry, market structure, cellular, price discrimination, nonlinear pricing, telecommunications

JEL Codes: L11, L13, L25, L96

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Introduction

This paper studies how market structure affects nonlinear pricing strategies using data from US cellular telecommunications markets in the mid to late 1990s. In particular, we look at how entry and differences in number of competitors affect the number of different pricing plans that cellular firms offer. In industries such as mobile communications, firms employ nonlinear pricing strategies to segment consumers by their demand for the products, here the volume of calls, and price-discriminate based on consumers' preferences for the product. The cellular industry experiences considerable entry in the second half of the 1990s after the Federal Communications Commission (FCC) awarded licenses to new spectrum for mobile communications services. By 1998, we observe significant variation in the amount of entry by Personal Communication Services (PCS) providers across cellular markets. The paper develops a simple model to predict the effect that such a change in market structure has on firms' nonlinear pricing strategies, in particular how many different pricing plans to offer to optimally exploit heterogeneity in consumer preferences. We then test the implications of the model using data on the behavior of cellular incumbents both prior and subsequent to the entry of PCS competitors.

For many subscription services, firms compete in menus of nonlinear tariffs. When firms offer such menus, the number of tariffs offered has important welfare implications. Introducing an additional tariff provides a better match with the tastes of some consumers, allowing firms to steal demand from their competitors through finer price discrimination. At the same time, each tariff adds fixed costs of administering the plan. Our theoretical model shows that the number of firms has an ambiguous effect on the number of tariffs offered, depending on the balance between strategic incentives to introduce tariffs and cost considerations of tariff introductions.

We use heterogeneity in the degree of entry across well-defined geographic markets to test its effect on the change in the number of plans offered by the incumbent providers. We find that incumbents introduce more calling plans in markets with more entrants.

This effect is not explained by demographic characteristics of these markets or firm-specific factors, suggesting that the strategic incentives dominate cost considerations. During the time period of our study, many cellular markets undergo a transition from an older, analog, technology to a newer, digital, technology. This transition allows us to also test the effect of market structure on technology adoption. We find that incumbents in markets with more entrants are more likely to upgrade their technology from analog to digital. Moreover, incumbents more drastically phase out analog tariffs in markets with more entrants, frequently offering the two technologies side-by-side during the transition. Overall, incumbents in markets with more competitors make the transition to digital technology sooner and offer a greater variety of tariffs on the new technology than incumbents in markets with fewer competitors.

Predictions from previous theoretical models of nonlinear pricing in oligopolies are limited and focus on the relationship between market structure and the curvature of nonlinear pricing schedules. Among exclusive agency models, Stole (1995), for example, derives firms' optimal nonlinear pricing strategies to exploit consumer heterogeneity in a single dimension of preferences, such as consumers' vertical taste for quality.[1] In equilibrium, he finds that firms serve a product of optimal quality to consumers with either low or high quality valuations, but distort downward the quality of the product they offer to consumers with intermediate quality valuations. Increased competition lowers price schedules toward marginal cost, increasing market coverage and reducing quality distortion.[2]

Stole (1995), as does the majority of the theoretical literature on nonlinear pricing, assumes positive entry costs for firms but zero fixed costs per quality level offered. As a result, firms offer fully nonlinear pricing schedules defined over a continuum of qualities, allowing an examination of the effect of nonlinear pricing on quality dispersion and

[1] Armstrong and Vickers (2001) and Rochet and Stole (2002) are two rare exceptions that analyze a monopolist or duopolist's nonlinear pricing strategy in the context of more realistic, multi-dimensional consumer preference heterogeneity.

[2] Similar results arise in other differentiated products, oligopolistic setups, including Spulber's (1989) location model and Gal-Or's (1988) model of product differentiation using consumer taste parameters.

distortion. The implications of these models have been tested in a number of empirical contexts. Rysman and Busse (2004) analyze the effect of market structure on the shape of the advertising price schedules offered by yellow pages directories and McManus (2003) provides empirical evidence for the "no distortion at the top" feature predicted by theory using data on quantity discounting in coffee shop pricing.[3] These papers abstract from the fact that in practice, we rarely observe continuous nonlinear pricing functions being offered to consumers. In many industries, such as electricity, Internet service provision, telecommunications and subscription services, firms instead employ menus of two-part tariffs rather than a continuous nonlinear pricing function. One possible way to model pricing that takes the form of menus of two-part tariffs is by introducing a fixed cost of offering each quality level into the firm's pricing problem.

Wilson (1993) does so in a monopoly framework to show that as the number of two-part tariffs increases, in the limit, the model converges to that for a fully nonlinear tariff. Furthermore, he finds that in his set-up, relatively few two-part tariffs are necessary to realize most of the profit gains from a completely nonlinear tariff. Miravete (2004a) confirms this result empirically in the early cellular industry, estimating that the mean foregone profits from not offering an additional calling plan amount to four percent of the profits attainable with a fully nonlinear tariff. Miravete's results assume that there are no cost effects on the part of either provider or consumers in offering additional tariffs, which we investigate below. We extend Wilson's (1993) work to the case of an oligopoly using a setup similar to that of Oren, Smith, and Wilson (1983) who analyze an oligopolist's optimal choice of a fully nonlinear tariff in a Cournot equilibrium. We assume instead that firms incur a fixed cost of offering a particular pricing plan. As a result, the firm chooses both the number of two-part tariffs to offer and the prices that characterize each tariff.

Our theoretical results predict that for a given number of tariffs, as additional firms enter the market, the fraction of consumers that participate in the market increases and total

[3] Several recent empirical papers (Miravete and Röller 2004, Reiss and White 2001) estimate structural models of nonlinear pricing to uncover the underlying consumer preference functions and then evaluate the effect of policy changes on consumer demand.

industry profits and welfare increase. While we do not solve explicitly for the equilibrium number of tariffs to offer in equilibrium, the model highlights two opposing effects that determine how the optimal number of two-part tariffs varies with the number of competitors a firm faces.

First, as firms "fill up the space" of nonlinear contracts, they better address consumer heterogeneity and price-discriminate more finely. By introducing an additional tariff, a firm is able to steal those consumers from its competitors for whom the additional pricing plan provides an overall better match between consumers' tastes for volume of calls and plan specifics than the portfolio of pre-existing plans. This strategic effect to introduce additional calling plans increases with the number of competitors who in equilibrium capture equal shares of consumers. At the same time, adding an additional tariff requires the firm to incur additional fixed costs, which offsets the profit gains due to business stealing. With more competitors in the market, per-firm revenues to cover these fixed costs are lower. The relationship between the optimal number of two-part tariffs and the number of competitors is thus ambiguous: a firm introduces additional tariffs if the strategic effect dominates the fixed cost effect, but may reduce its tariff offerings if each tariff by itself is very costly to maintain.

Our work relates to the literature on optimal product variety, with the main difference being that in nonlinear pricing, price is the characteristic of the product over which the firm differentiates, resulting in different welfare implications. Similar to our results, however, the theoretical literature stresses two main influences on a firm's choice of product variety.[4] First, it may be profitable to offer multiple product varieties to better satisfy heterogeneous customers' tastes and thus increase revenues, as long as such revenue gains outweigh any losses in economies of scale in the production of each variety. Second, firms may adjust the number of product varieties they offer in response to entry (Judd 1985) or to deter future entry by preempting the product space (Schmalensee 1978, Bonanno 1987). Berry and Waldfogel (2001) empirically test these

[4] See Spence (1976) and Dixit and Stiglitz (1977) for general discussions. Lancaster (1990) provides an excellent survey of the relevant literature.

models by investigating the effect of consolidation after the 1996 Telecommunications Act on station variety in the radio market. They find that mergers reduce station entry and increase the number of formats available per station, consistent with higher concentration increasing overall variety.

Since our theoretical model demonstrates that the number of competitors has an ambiguous effect on tariff variety, the actual effect is an empirical question. We offer empirical evidence from the mobile telecommunications industry of the late 1990s.[5] Our theoretical model assumes fixed costs of offering additional calling plans as the justification for firms competing in menus of two-part calling plans. In the cellular industry, these fixed costs include costs of developing, marketing, and administering the plan for the firms as well as increased time spent by consumers understanding and comparing the plans. Experimental evidence presented in Iyengar and Lepper (2000) suggests that such consumer optimization costs may be significant and that "choice-overload" by consumers may lower firm profits.

We use detailed data on the pricing plans offered by cellular incumbents in 1996 and in 1998 to test the effect of entry on tariff variety by comparing the experiences of cellular incumbents across different geographic markets over this time period. Starting as duopoly markets prior to mid-1996, the geographic markets experience different levels of entry by winners of the FCC's PCS auctions that developed their licenses for service by 1998. Variation in the introduction of service is due to two main factors, which are arguably exogenous to tariff choices. A significant fraction of the licenses are left undeveloped due to the bankruptcy of winning bidders. In addition, there is variation in market geographic features that affect the time required to build a network of wireless transmission towers that is sufficiently large to provide wireless service of a satisfactory quality.

[5] The setting complements earlier papers on pricing in the cellular industry, including Parker and Röller (1997) and Busse (2000) who focus on the early cellular industry of the 1980s when competition was confined to duopoly markets.

During the period of our sample, the mobile communications industry is transformed not only by changing market structure, but also by the introduction of marketable digital transmission technologies. As a by-product we also provide evidence of the effect of market structure on technology adoption, an area that has received limited attention in the empirical literature on technological diffusion.[6]

Our empirical work compares the number of plans introduced by the cellular incumbents across markets with varying amounts of entry. We find that incumbents introduce more plans for digital service and simultaneously eliminate more plans for analog service in markets with more entrants. Most carriers have either fully replaced or begun the transition toward full replacement of the older analog technology with the newer digital technology by 1998. We find that the presence of additional competitors spurs this technology upgrade: firms phase out tariffs based on the old technology and introduce tariffs based on the new technology more fully in markets with more competitors. Our theoretical model predicts that greater fixed costs of offering a calling plan should have a negative effect on the number of tariffs offered and that increased competition should exacerbate this effect because costs are duplicated across more firms. Using advertising cost data across our geographic markets we find consistent, but not statistically significant, evidence in support of this.

We also find an effect of entry on the technology transition itself. In markets with more entry, incumbents are more likely to adopt the digital technology controlling for other factors and instrumenting for the endogeneity of entry. We therefore find both a direct effect and an indirect effect, via technology choice, of entry on the number of plans offered.

[6] There are a number of theoretical studies, for example Reinganum (1981), Riordan (1992), and Götz (1999), that analyze the effect of market structure on the speed of technological diffusion and technology adoption. The empirical literature focuses primarily on measuring the role of firm characteristics and first-mover advantages in technology diffusion, but not on assessing the effect of market structure on technology adoption per se.

The remainder of the paper proceeds as follows. In the next section we discuss a theoretical model relating number of competitors and tariff variety choice. In the following section we provide background on the wireless services market during the time period of our study and describe the data we employ. We then discuss our empirical results and conclude.

Theoretical Model

In this section, we present a simple model to demonstrate the major tradeoffs that underlay an oligopolist's pricing decisions when firms compete for heterogeneous consumers using menus of two-part tariffs. We extend previous models of nonlinear pricing (Oren, Smith, and Wilson 1983, Wilson 1993) to consider the effect that competition has on the optimal number of tariffs each firm offers.

Set-Up

We consider a two-stage game between J symmetric firms that compete in a market with heterogeneous consumers. In the first stage, firms simultaneously choose the number, $n-1$, of two-part tariffs to offer in the second period. In the second stage, they choose the fixed fee and per-unit price for each two-part tariff given the number of tariffs chosen in the first stage. Consumers' preferences differ along a single dimension and we assume that their types, t, are uniformly distributed on [0,1]. As in Wilson (1993), type t's demand function is $D(p,t) = t[1-p]$.

We assume that firms face marginal per-unit costs of zero and a fixed cost per plan of K that is independent of the number of consumers choosing the plan. It is the presence of fixed costs of offering additional plans that induces firms to offer a menu of two-part tariffs rather than a fully nonlinear tariff. These costs could arise on the firm side in the form of marketing expenses or administrative costs or on the consumer side in the form of additional complexity of comparing costs under different plants.[7] While we have chosen to model the fixed per-tariff cost on the firm side, it is equivalent to decrease each buyer's willingness to pay by a fixed cost that is a linear function of the number of tariffs available.[8]

Figure 1 provides evidence that calling plans involve fixed marketing costs and exhibit economies of scope on the provider side. The figure plots 1996 and 1998 marketing expenditures per plan against the total number of plans offered by the provider across all markets for eleven of the sample firms.[9] We also include a fitted line that predicts marketing expenditures per plan as a function of a quadratic expansion of the number of plans. This fitted line lies between two extreme cases: a horizontal line that shows marketing expenditures per plan in the absence of economies of scope, and a steeply declining curve that represents the case of no incremental fixed costs from offering an additional plan beyond the provider's initial marketing expenditures. Thus, each additional plan adds some incremental costs, albeit at a decreasing rate. On the consumer side, menu costs or plan evaluation costs are more difficult to measure. Anecdotal evidence (Boney 1997, Marshall 1996) suggests, however, that they are important.

The contribution to firm *j*'s profits from a customer of type *t* purchasing its *i*-th tariff is:

$$\Pi_i^j(t) = p_i^j D(p_i^j, t) + P_i^j \quad i = 1, 2, \ldots n-1 \tag{1}$$

[7] An explanation sometimes suggested for why firms offer a menu of two part tariffs is that cellular firms exploit consumers' inability to predict their demand correctly by locking them into contracts. For example, consumers may not know the variance of their usage and "overbuy" to be safe, or alternatively, they may be too conservative in estimating their usage. In this case firms make money on consumers going over their expected usage by offering convex pricing plans. While this may be an explanation for why cellular firms require subscribers to pre-commit to a convex pricing plan, it does not explain why they require them to commit to a two-part tariff rather than a fully nonlinear tariff.

[8] Such a fixed cost does not affect the consumers' marginal willingness to pay, leaving the demand function unaffected. However, it will affect consumers' choice of whether to purchase at all. Firms would need to compensate consumers for this cost by reducing the fixed fees (across all two-part tariffs) proportionally, the equivalent of an additional fixed cost per tariff on the firm side.

[9] Marketing expenditures per plan are based on the total number of plans offered across the 100 markets in our sample.

where p_i^j is the marginal price and P_i^j is the fixed fee for firm *j*'s *i*-th tariff. These are ordered so that $P_i^j < P_{i+1}^j$ and $p_i^j > p_{i+1}^j$. The $i = 0$ tariff represents the option of purchasing an outside good at cost P_0^j and p_0^j.

Firm's Optimization Problem

Firm *j* chooses *n*–1 pairs of marginal prices and fixed fees, $\langle p_i^j, P_i^j \rangle$, *i*=1,2,…,*n*–1, to maximize aggregate profits across its set of two-part tariffs:

$$\Pi^j = \sum_{i=1}^{n-1} \left[\int_{t_i^j}^{t_{i+1}^j} \Pi_i^j(t)dt - K \right]. \tag{2}$$

Because the customers' demand functions are ordered by their types, the set of types *t* choosing the *i*-th tariff is an interval $t_i^j < t \le t_{i+1}^j$ where $t_0^j = 0$ and $t_n^j = 1$ are the boundaries of the type space. The firms' choices of prices and fixed fees determine the cut-off points, t_i^j, that make a consumer indifferent between tariffs *i*–1 and *i*:

$$\begin{aligned} & P_i^j - P_{i-1}^j = \int_{p_i^j}^{p_{i-1}^j} D(p, t_i^j)dp \\ \Rightarrow \quad & P_i^j = P_0^j + \sum_{k \le i} \int_{p_k^j}^{p_{k-1}^j} D(p, t_k^j)dp. \end{aligned} \tag{3}$$

This expression incorporates the outside option by setting consumer surplus for consumers that are indifferent between the outside good and the first tariff, with a type of t_1^j, equal to the amount attained from purchasing the outside good.[10]

[10] Note that menu costs on the consumer side (such as the cost of evaluating available cellular plans) would require that the firm decrease the fixed fees on all of the inside goods so as to keep consumers indifferent between them and the outside good so that firm profits are reduced by an equivalent amount. This is why the effect of such menu costs is equivalent to the role of the fixed cost per plan, K, in our model.

Second-Stage Oligopoly Equilibrium

To compute the oligopoly solution, it is convenient to express the firm problem in terms of a choice of *n*–1 pairs of marginal prices p^j and type cutoffs t^j:

$$\Pi^j = \sum_{i=1}^{n-1}\left[\int_{t_i^j}^{t_{i+1}^j} p_i^j D(p_i^j, t)dF(t) + \overline{F}(t_i^j)\int_{p_i^j}^{p_{i-1}^j} D(p, t_i^j)dp - K\right],$$

$$\text{with} \quad \overline{F}(t_i^j) = \sum_{k=i}^{n-1}\int_{t_k^j}^{t_{k+1}^j} dF(t) = F(t_n^j) - F(t_i^j) = 1 - t_i^j. \tag{4}$$

The first term within the summation represents the variable-fee revenues received from consumers on the *i*-th tariff. The second term indicates that all types choosing a tariff $i' \geq i$ pay a fixed-fee increment of $P_i - P_{i-1}$. Applying a change of variables from type *t* to the corresponding quantity consumed, *q*, yields:

$$\Pi^j = \sum_{i=1}^{n-1}\left[\int_{q_i^j}^{Q_i^j} p_i^j q dF(t(q)) + \overline{F}(t(q_i^j))\int_{p_i^j}^{p_{i-1}^j} D(p, t_i^j)dp - K\right],$$

$$\text{with} \quad \overline{F}(t(q_i^j)) = \sum_{k=i}^{n-1}\int_{q_k^j}^{Q_k^j} dF(t(q)) = F(t(q_n^j)) - F(t(q_i^j)), \tag{5}$$

where $q_i^j = t_i^j(1-p_i^j)$ and $Q_i^j = t_{i+1}^j(1-p_i^j)$ define the volume band, $q_i^j \leq q \leq Q_i^j$, for consumers that choose the *i*-th tariff. Note that the quantity that the indifferent type t_i consumes on tariff *i*-1, Q_{i-1}, is less than the quantity she will consume on tariff *i*, q_i, because this marginal consumer faces a lower marginal price, but higher fixed fee, on the i th tariff than on the $i-1$ st tariff.

We solve for a Cournot oligopoly in the spirit of Oren, Smith, and Wilson (1983), using an equilibrium concept in which each firm takes as given the "cumulative" market share of customers that order *q* units or less.[11] The policy of firm *j* is thus defined by a function

[11] We choose this strategic variable because alternative strategic variables suggested by Oren, Smith, and Wilson (1983) have unappealing features for our application. Taking as given the percentage of each customer type completely loyal to other firms leads to firms behaving as monopolists and does not reflect

$T^j(q)$, which equals the fraction of buyers purchasing q units or less. Firm j will predict the total fraction of buyers purchasing q units or less from its competition as $Y^j(q) = \sum_{k \neq j} T^k(q)$, and the density of consumers that the firm itself captures reduces to $F(t(q)) - Y^j(q)$.[12]

After applying symmetry, the necessary condition for the optimal choice of marginal price p_i is given by:

$$\begin{aligned} 0 = &\int_{Q_i}^{q_i} q((1-p_i)^{-2} - \dot{Y}(q))dq - t_{i+1} p_i Q_i ((1-p_i)^{-1} - \dot{Y}(Q_i)) \\ &+ t_i p_i q_i ((1-p_i)^{-1} - \dot{Y}(q_i)) - t_i \dot{Y}(q_i) \int_{p_i}^{p_{i-1}} t_i (1-p) dp \\ &- t_i (1-p_i)(t_n - t_i + Y(q_i) - Y(q_n)) + t_{i+1}(1-p_i)(t_n - t_{i+1} + Y(q_{i+1}) - Y(q_n)). \end{aligned} \quad \textbf{(6)}$$

The impact of a price increase for an oligopolist (i.e. when J>1) differs from that for a monopolist since the firm only serves a fraction of the density of consumers. This leads to the following four effects. First, the density of consumers served by the other firms reduces the gain to the firm from inframarginal consumers on tariff i, as captured by the first term in the first-order condition. Second, increasing the per-unit price on tariff i leads both to consumers on tariff i decreasing the quantity consumed and to competitors capturing a larger share of consumers, the typical effect of a marginal change in price. The second and third terms in equation (6) together represent the revenue lost due to this demand response.

The last three terms in equation (6) represent the effects on revenue of changes in fixed fees applied to the firm's share of demand. A price increase implies that the firm loses revenues on fixed fees from consumers shifting their purchases to competitors (the third to last term). In addition, an increase in the per-unit price on tariff i in isolation requires a

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the fact that significant switching occurs in the cellular industry. Using the number of orders at each dollar value as the firm's strategic variable might reasonably reflect competition in the cellular market, but as Oren, Smith and Wilson point out the solution to this model is "complicated and uninterpretable." The strategic variable we consider has the advantages of both reflecting cellular competition and being easily interpretable.

[12] Thus in equation (5), $F(t(q))$ is replaced by $F(t(q)) - Y^j(q)$ and $\overline{F}(t(q_i^j))$ is replaced by $\overline{F}(t(q_i^j)) - \overline{Y}^j(q_i^j)$, which equals $\sum_{k=i}^{n-1} \int_{q_k^j}^{Q_k^j} d(F(t(q)) - Y^j(q))$, or $(F(t(q_n^j)) - Y^j(q_n^j)) - (F(t(q_i^j)) - Y^j(q_i^j))$.

decrease of the fixed fee on tariff i and increases in the fixed fees associated with all tariffs above i to ensure that the boundary types t_k, k=i,…, n–1, remain indifferent between adjacent tariffs (the last two terms).

In a symmetric Cournot equilibrium, each firm earns a share $\frac{1}{J}$ of customers of type $t(q)$ and the cumulative density of consumers captured by the firm's competitors simplifies to $Y(q) = \frac{J-1}{J} t(q) = \frac{J-1}{J}(1-p_i)^{-1}$. The first order condition thus reduces to:[13]

$$0 = \frac{1+(J-3)p_i}{2J}(t_{i+1}^2 - t_i^2) - \frac{(J-1)[2(p_{i-1}-p_i)-(p_{i-1}^2-p_i^2)]}{2J(1-p_i)} t_i^2 + \frac{1}{J}(1-p_i)(t_{i+1}-t_i-(t_{i+1}^2-t_i^2)). \quad \textbf{(7)}$$

The firm's second choice variable consists of the cutoffs that define customer types for each tariff. Differentiating firm j's profit function with respect to t_i^j and again applying symmetry, we obtain the necessary condition for the optimal choice of the boundary type t_i:

$$0 = -p_i q_i (1-\dot{Y}(q_i)(1-p_i)) + p_{i-1}Q_{i-1}(1-\dot{Y}(Q_{i-1})(1-p_{i-1})) - (1-\dot{Y}(q_i)(1-p_i))\int_{p_i}^{p_{i-1}} t_i(1-p)dp + [J^{-1}-(t_i - Y(q_i))]\int_{p_i}^{p_{i-1}}(1-p)dp. \quad \textbf{(8)}$$

Firms choose each boundary type to balance four effects corresponding to the four terms in the first-order condition. First, moving the cutoff decreases per-minute revenues due to consumers shifting away from the i-th plan (the first term). Second, moving the cutoff increases per-minute revenues at the same time due to consumers shifting to plan i-1 (the second term). The last two effects of moving the cutoff result from changes in fixed-fee revenues. The density of consumers on the ith tariff decreases and the density of consumers on the i-1th tariff increases affecting the fixed fees collected on these two tariffs (the third term). Finally, revenues per consumer on the ith tariff increase due to an

[13] When $J = 1$, this simplifies to the monopoly condition given in Wilson (1993) of $p_i = 1-(t_{i+1}+t_i)/2$.

increase in its fixed fee (the fourth term). Since each firm takes as given its share of consumers purchasing a given quantity or below, the number of firms in the market only scales each of these four effects by the same amount. Consequently, after substituting for q, $Y(q)$, and $\dot{Y}(q)$, this expression is independent of the number of firms:

$$0 = t_i[(p_{i-1} - p_{i-1}^2) - (p_i - p_i^2)] + \frac{(1-2t_i)}{2}[(2p_{i-1} - p_{i-1}^2) - (2p_i - p_i^2)]$$

$$\text{or} \quad t_i = 1 - \frac{1}{2}(p_i - p_{i-1}). \tag{9}$$

First-Stage Analysis

The optimal solution for the per-minute prices and boundary types allows us to compute profits in the second stage as a function of the number of two-part tariffs. In the first stage, the firms choose the number of tariffs, n-1, to maximize their profits in both stages subject to a fixed cost per tariff of K. Setting up the first-stage equilibrium is complicated by the fact that the second stage yields a tractable solution only for the case in which firms are symmetric in the number of plans that they offer. Because of the multiplicity of possible equilibria and the difficulty in determining the optimal "off-equilibrium" response by firms, we do not explicitly solve for the first stage equilibrium, but choose instead to describe qualitatively the factors each firm considers.

Table 1 shows the total profits, per-firm profits, fraction of consumers served and consumer welfare allowing the number of firms to vary from two to six with each firm offering two, four or six tariffs. For a given number of firms, total industry profits increase in the number of tariffs. As the firms offer more tariffs, they fill in the tariff space more finely and price discriminate more effectively as evidenced by the fact that consumer welfare declines even though a larger fraction of consumers purchase. The profit increases diminish fairly quickly though, so that little additional gain is achieved by offering more than six tariffs. The welfare implications of tariff variety are thus different than those for product variety since consumer welfare actually declines as more tariffs are added. However, total welfare increases as tariffs are added since firms extract additional profits while more closely matching consumer tastes and expanding the market size.

Table 1 also demonstrates that for a given number of tariffs, industry profits increase and consumer welfare decreases in the number of firms. As the number of firms increases, firms compete to bring more previously unserved consumers onto the "low" tariffs by lowering the equilibrium fixed fees on all but the highest tariff. At the same time, they increase the marginal prices on all but the highest tariff, since firms take as given other firms' share of consumers on a particular plan. That is, there is increased competition to move new consumers to "lower" tariffs than to attempt to steal share from rivals within a particular tariff.[14] Firms gain more from the higher per-unit fees than they lose on the lower fixed fees so that consumer welfare declines in the number of firms, despite the expansion of the market resulting from the lower fixed fees, and industry profits increase. Profits per firm, however, decline as more firms enter the industry because the firms must share the aggregate profits with more rivals.

Although we do not explicitly solve for the first-stage equilibrium of this model, we can identify two main effects of a change in the number of firms on the equilibrium number of tariffs from Table 1. First, as the number of firms increases, the incentive to deviate and add additional tariffs increases. By adding an appropriately designed additional tariff, the oligopolist can capture a segment of demand that it and its rivals do not currently serve. It can "fill in the space" and better meet the heterogeneous needs of that segment. Similar to cartel behavior, the deviator grabs the entire demand in that segment rather than sharing this demand with all other firms. For example, in a two-firm equilibrium with two tariffs, each firm earns profits of 0.0687. If one of the two firms were to deviate and offer three tariffs instead, it could earn profits of up to 0.1382 by slightly undercutting the other firm all along the distribution of consumers for a net gain of 0.0695. As the number of competitors rises, the maximum net gains from deviating increase because per-firm profits decline, while industry profits increase. For example,

[14] The marginal price and fixed fee changes as a function of the number of competitors is non-monotonic so that no generalizations can be made.

with three firms, the gains from deviating and offering three rather than two tariffs increases to 0.0963 from 0.0695. Figure 2 illustrates this effect in deviating from offering two to offering three tariffs for two through ten firms. The same pattern is true in deviating from offering $n+1$ tariffs from offering n tariffs for $n>2$. This strategic effect leads to more tariffs as the number of firms increases.[15]

Second, as the number of firms increases, the fixed costs of tariffs are duplicated across firms. Each firm must cover the same fixed costs per tariff, but sells to a smaller share of the market, reducing the amount of profits it earns per tariff. All else being equal, this leads to fewer tariffs being offered as the number of firms increases. The net effect depends on the magnitude of the fixed costs relative to the strategic effect and the model thus predicts an ambiguous relationship between number of firms in a market and number of plans offered by firms.

Mobile Telecommunications Markets in the mid 1990s

The data used in this study comes from Kagan World Media, a telecommunications consulting firm. It consists of two snapshots of the universe of wireless contracts offered in the 100 largest US cellular markets at the time, which encompass approximately 60 percent of the US population (the shaded areas in Figure 3 show the markets in our study).[16] The first snapshot is as of February 1996, and the second one as of March 1998. As discussed below, this data is ideally timed to study the response by incumbents to the onset of new competition since between these two periods the market structure in wireless telecommunications changed significantly.

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[15] Note that economies of scope in tariff costs, as we find in Figure 2, would imply that it is more costly to move from offering two tariffs to offering three than it is to move from offering three tariffs to offering four and so on so that under economies of scope the strategic effect is diminished but still remains.

[16] The data capture only residential (not business) plans. Approximately 75 percent of cellular users are retail consumers according to Strategy Analytics (*Cellular Service Trends Industry Report*, 2000) and IDC (Burgeoning Bluetooth, *IDC Bulletin*, 2000).

Industry Background

The US cellular phone industry has its origins in 1981 when the Federal Communications Commission (FCC) awards two licenses per cellular market area (CMA) to provide cellular telephone services in a set of 306 metropolitan markets[17] and 428 FCC-designated rural markets covering the entire country (see a map of these areas in Figure 3). The local wireline company, which is generally the Regional Bell Operating Company in the metropolitan markets and a rural telephone company otherwise, receives one license to a band of spectrum. The second license is awarded to a non-telephone company. In October 1983, Ameritech Mobile initiates the first service resulting from these licenses in the Chicago market.

The duopoly structure exists until 1994 when the FCC begins auctioning off personal communications services (PCS) spectrum. The geographic market definition used for PCS spectrum differs from that applied to cellular markets. 51 Major Trading Areas (MTAs) divide the country into regions that include multiple cities or states. MTAs are further subdivided into a total of 493 Basic Trading Areas (BTAs). The bold lines in Figure 3 display the MTAs, which fully contain the CMAs. A BTA is of the same size or slightly larger than the corresponding CMA and in most cases fully contains the cellular market. Upon activation of the PCS licenses, the cellular incumbents compete directly with PCS entrants in their entire market area. Between December 1994 and January 1997, the FCC sequentially auctions off the PCS spectrum in six blocks, two of which cover MTAs while the remainder are for the smaller BTAs. In total, 2074 licenses were initially auctioned.

Concurrently with the allocation of PCS licenses, cellular incumbents witness the entry of Nextel Communications due to its transition from providing mobile radio services to offering competing wireless services. Nextel begins a national rollout of its service in the Chicago market in September 1996. By 1998, Nextel has entered 65 of the 100 largest

[17] The market definition followed metropolitan statistical areas as delineated by the Census Bureau in its 1980 Census of Population.

cellular markets. Despite Nextel's initial focus on business customers, we treat it as a viable competitor to the cellular incumbents, similar to the PCS entrants.

By 1998, cellular incumbents therefore face potential entry of one specialized mobile operator and up to six PCS service providers. The number of competitors actually operating in a given market subsequent to the auctions' conclusion is driven by two main factors. First, a significant number of licenses, in particular those awarded to small businesses are initially left undeveloped. Several of the largest winning bidders in restricted small business auctions "overbid," forcing them into bankruptcy soon after the auction ended. The licenses from bankrupt or insolvent bidders remain undeveloped while their status is resolved. In April 1999, the FCC re-auctions most of these 347 undeveloped licenses.[18]

Second, there is a significant lag, on the order of one year or more, between the initial award of a license and the initiation of service in the market while the carrier puts in place a network of towers to broadcast signals to its users' mobile phones. This time lag is commonly referred to as the "build-out" delay. Table 2 shows the PCS launch dates by market for the largest 100 markets over the period from 1995 to 1999. Since Nextel's network is cellular-like and consists of a dense grid of transmitters, its national rollout of service is constrained by similar build-out requirements.

While it is difficult to precisely characterize the build-out delay, characteristics of the market affect the size and difficulty of constructing the tower network required to offer PCS service of sufficient quality and, consequently, the time it takes to deploy service in that market. To enforce the development of the awarded licenses, the FCC also requires PCS licensees to meet specific coverage requirements. These coverage requirements amount to providing adequate service to at least between 25 and 33 percent of the market area's population, depending on the license, within a five-year time window after the award of the license. The build-out delay is affected by factors such as the market's

[18] The largest single source of undeveloped licenses is due to NextWave's bankruptcy, leading to the return of 95 licenses. As of 2002, these licenses are still not developed.

subscriber base, its area and terrain, and zoning requirements, providing exogenous variation in the number of competitors across markets. These factors suggest instruments to control for potential endogeneity of entry across markets. Endogeneity would arise if firms chose to first build out less competitive markets, one feature of which are incumbents' pricing strategies, including the number of pricing plans offered.

To predict the delay in building out a market, we use measures of market size and geographic characteristics. The CMAs' 1999 population from the 2000 Census of Population captures the market's potential subscriber base, which has an ambiguous effect on entry. A higher potential market size makes entry more attractive, while at the same time making it more difficult to satisfy build-out requirements. We collect information on the CMAs' average elevation and standard deviation of elevation as a measure of variability in the terrain and thus of geographic impediments to constructing a network of transmission towers in the area. They are derived from grid-based elevation data collected by the US Geological Survey. We retain those elevation measures that correspond to point locations within each CMA to compute the average and standard deviation of the elevation. Last, we include the percent of the CMA's area that corresponds to the area's central cities, as defined by the 2000 Census of Population, as a measure of the degree of urbanization of the market, which would facilitate satisfying build-out requirements.

Because of the variation in entry and the clear definition of tariffs and markets in this industry, it offers an attractive setting in which to test the effect of market structure on tariff variety. The available data is ideally timed to do so. The first wave of data from February 1996 marks a point in time shortly before the PCS operators start the launch of commercial service in the markets that they secured in the FCC auctions. As of early 1996, the sole providers of wireless telephone services in all but two of the markets covered by the data continue to be the incumbent cellular duopolists.[19,20] The second

[19] The only exceptions are the Baltimore and Washington CMAs, which were dropped from the estimation sample.

[20] Firms that re-sell wireless service on a licensed carrier's network are also present during the time of our data set, but represent a small portion of the market throughout. According to *RCR Wireless News*, the top 20 resellers together have 747,994 subscribers or approximately 1.96 percent of the market in 1996,

snapshot of contracts is from March 1998, when a majority of the markets have already experienced the entry of one or more PCS providers.[21]

Wireless Service Plans

Most wireless service is sold under nonlinear pricing schemes or "three-part tariffs." Consumers pay a monthly fee for which they get a number (which may be zero) of included peak and off-peak minutes. Usage above the number of minutes included in the plan is charged at a per-minute rate. Both incoming and outgoing calls count against the customer's usage. In addition, various additional charges may apply, such as charges for placing a call that terminates outside the calling area specified in the consumer's contract.

The network of markets covered by the provider's licenses limits a plan's calling area. During the time period of our study, the network of markets covered by the cellular incumbents' licenses is, in most cases, small. Across the 100 markets in our data, 24 unique providers offer cellular service in 1996. Of these, 15 firms operate licenses in at most five of the top 100 cellular markets, while only five carriers (Air Touch Cellular, AT&T Wireless, Bell Atlantic Mobile, GTE Mobilnet and Southwestern Bell Mobile) offer service in 15 or more of these markets. One effect of the small size of cellular networks is that the costs for providers to complete calls that terminate or originate outside their network area are substantial because of fees to access other providers' networks. Cellular carriers incorporate these costs into their pricing structure by offering local calling plans only, where the consumer's local calling area is her CMA and additional charges apply to all calls originating or terminating outside the CMA.

955,083 subscribers (1.96 percent market share) in 1997, and 1,152,315 subscribers or 1.89 percent of the market in 1998.

[21] To construct the 1998 snapshot, which continues to use cellular market areas as the relevant market definition, Kagan World Media mapped the PCS providers' BTA and MTA market areas to the corresponding CMAs to derive an accurate measure of the set of competitors and their tariff offerings in each market.

With the entry of PCS firms and the gradual build-out of larger networks, carriers begin introducing calling plans with larger regional or nationwide calling areas. Such calling-plan families by coverage area serve as additional tariff varieties to induce customer sorting by usage area.[22] The plans offered by cellular incumbents that we observe in the data between early 1996 and early 1998 do not yet reflect the introduction of plans with wider geographic reach, but solely reflect changes in the variety of cellular incumbents' offerings of local calling plans.[23]

To capture market-level cost differences in promoting calling plans, we complement the pricing data with data on advertising costs. Since television advertising does not necessarily differ across markets and cost data on newsprint advertising is only sparsely available, we focus on radio advertising. Although cellular carriers use multiple channels to advertise calling plans, the radio cost data should provide an accurate proxy to the extent that the different channels are substitutes. Radio advertising cost data is available from the *Marketer's Guide to Media* at the level of television markets (DMAs). It measures the cost per rating point of men 18 and older for a 60-second spot in 1997. We use the advertising data as described in the empirical section below to test the role of tariff-level fixed costs in driving changes in a carrier's menu of calling plans, as predicted by the theoretical model.

[22] In January 1997, Nextel Communications is the first wireless service provider to eliminate roaming (charges for placing calls while traveling outside the local calling area), but not long-distance (charges for calls terminating outside the local calling area), charges for customers traveling within its digital network composed, at the time, of fifty metropolitan areas. AT&T Wireless introduces a flat-rate national calling plan without any roaming or long-distance charges, the Digital One Rate Plan, in May 1998.

[23] For a small subset of markets, the second wave of pricing data was only collected in September 1998. AT&T's Digital One Rate Plan is not offered in any of these markets as of that date. Bell Atlantic Mobile's regional plan is offered in five of these markets and was eliminated from the sample used in estimation.

Wireless Technologies

Beginning in the mid 1990s, the wireless industry undergoes not only a change in the competitive environment due to the introduction of PCS services, but also a gradual upgrading of its analog networks to digital technology. By allowing the cellular networks to handle a larger call volume, digital technologies improve the efficiency of spectrum use. This entails significant capacity increases for the providers, while at the same time improving the quality and reliability of service for the consumer. Furthermore, digital technologies allow for the addition of features such as call waiting, caller ID, as well as data and paging capabilities, introducing an additional vertical element to the service provision. By 1998, however, the coverage area of digital service across the US is limited. The fact that digital service relies on four different technology standards complicates the use of a digital phone when traveling due to a higher chance of inoperability.[24] Initially, therefore, analog service is still the better option for low-usage customers who use a cell phone for emergency purposes only, justifying why carriers may offer both technologies simultaneously.

The timing and form of digital deployment varies significantly across carriers. While in 1996, carriers exclusively employ analog or, in rare cases, immature digital technologies, by 1998 42 percent of all plan families are digital calling plans. Over the two-year period of our sample, however, only approximately eight percent of providers fully upgrade all of their analog plans to digital plans within a given market.[25] Thirty-four percent of providers have not yet begun digital deployment at all by 1998. The remaining 59 percent of providers offer customers within a given market a choice between analog and digital calling plans using two sets of calling plans that differ by technology.

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[24] The cellular and PCS providers use one of three digital technology standards, CDMA, TDMA, or GSM. Nextel uses Motorola's digital iDEN technology, which combined enhanced digital cellular and two-way radio technology in one standard.

[25] The FCC's rules require that all cellular carriers continue to provide analog service, a requirement that is scheduled to expire in 2008. However, the carriers are not required to offer new analog service plans. In contrast, other mobile telephony carriers such as the PCS service providers are not required to provide analog service.

Trends in the Number of Plans offered between 1996 and 1998

A typical set of calling plans in 1996 consists of, on average, 5.89 individual plans, ranging across providers from three to eight plans. These are generally analog plan groups. By 1998, firms have introduced a total of 128 digital plan families across the 98 markets, while continuing to offer 178 analog plan-groups. Relative to 1996, the number of plans in an analog plan-group decreases by 0.07 on average; however, the standard deviation of the change is large and amounts to 1.92 plans, reflecting an uneven adjustment in the number of analog service plans by carriers. A large fraction of providers offers both types of plans simultaneously. Consequently, despite the slight decrease in the average number of analog service plans offered, companies offer an additional 2.80 plans in 1998. This reflects the introduction of digital calling plans, which average 5.06 plans in those markets where digital service is available.

The detailed nature of our price data allows us to not only analyze changes in the menu of plans offered over the two-year period, but to also verify that such menu changes truly reflect the introduction or elimination of a tariff that differs significantly from the remaining plans. We focus on two features of cellular contracts that are central in differentiating plans from each other, the plan's monthly fixed fee and the included peak-minutes that the customer may use for no additional charge.[26] Along these two dimensions, the plan offerings differ significantly within a provider's portfolio, over time, and across plan technologies at the same point in time. We do not observe tariffs that are fully dominated by other tariffs in the provider's menu of offerings, or "foggy" tariffs, which are the subject of Miravete (2004b). Table 3 summarizes patterns in fixed fees and

[26] Additional contract features that are covered by the data include the number of off-peak minutes, the plan's activation and termination fees, overage charges for additional peak and off-peak minutes, as well as the availability of optional vertical services such as call waiting or voice-mail. Within a specific plan family in our data, the contracts' features differ primarily in the peak and off-peak overage charges and in the included number of peak and off-peak minutes. Ninety-eight percent of the plan families did not exhibit any within-family differences in activation and termination fees or contract duration, and all plan groups offer identical vertical features including call waiting, call forwarding, three-way calling, and voice mail and use the same definition of peak and off-peak hours.

included number of peak-minutes for the two years covered by the data, both overall and within providers.

The table indicates significant overall variation in both fixed fees and included peak-minutes, as indicated by the large ranges of values and standard deviations. In moving from 1996 to 1998, the standard deviations for both features increase for analog plans, suggesting that the newly introduced plans fill in the space of tariffs as opposed to duplicating existing tariffs. Furthermore, the range of monthly fees has increased, while its mean and median have fallen. Together, these statistics suggest that between 1996 and 1998, providers adjust the set of tariff offerings in two ways. On the one hand, providers expand the available product space by offering more expensive packages than previously. On the other hand, carriers fill in parts of the lower-priced product space more densely, a space aimed at the majority of cellular users who have a relatively modest monthly demand for cellular services.

Similar patterns hold for fixed fees and peak-minutes within a provider's family of plans. In unreported results, we also find significant differences in the menus of calling plans offered by the same provider in different markets indicating that each of the carriers tailors its plans significantly to local markets. Within providers, the coefficient of variation for fixed fees ranges between 21 and 37 percent and for peak-minutes between 36 and 66 percent. This is evidence that variation in number of plans across markets is not primarily due to firm features, a possibility we explicitly control for in our estimation.

Demand for Cellular Services

While market-level pricing data allows us to control for provider-specific characteristics that could affect the change in plan offerings between 1996 and 1998, exogenous demand factors may also affect a provider's choice of menus. Following earlier studies of the cellular industry, such as Busse (2000) and Miravete and Röller (2004), we capture the demand for mobile telecommunications services by market size variables, primarily the market's population, as well as demographic variables, including mean commuting time in the market, household income, and educational attainment. Average commuting time in minutes is included as a crude measure of the additional attractiveness of a cellular phone to frequent drivers. Since changes in providers' tariff offerings may reflect heterogeneity in demand, we also compute Herfindahl-type indices for the heterogeneity in income, educational attainment, and commuting time in each market, capturing the probability of two randomly selected MSA residents falling into the same demographic category. Table 4 provides descriptive statistics for these variables based on data from the 2000 Census of Population. There is considerable variation in the markets' characteristics; they range in size, for example, from New Bedford, MA with a population of 175,198 to the Los Angeles metro area with a population of 9,519,338.

Growth in demand may, in part, be responsible for how many additional plans a carrier introduces in a given market. To analyze the determinants of changes in the cellular incumbents' service offerings, we would ideally use measures of how each market's cellular subscriber base has changed over the two-year time period of our sample. Wireless services grow in popularity over the time of our sample. The Cellular Telecommunications and Internet Association (CTIA) estimates that nationwide, the number of cellular subscribers has increased from 38.2 million in June of 1996 to 60.8 million in June of 1998.[27] Less information is available, however, on growth in the subscriber base at a disaggregate market level. Consequently, we rely upon demographic information from the Census of Population to proxy for differences in cellular demand across markets, but do not control for differences within markets over time.[28]

In summary, the data available to us consists of information from 98 markets on the menu of plans offered by each of the two cellular incumbents, the cost of radio advertising in

[27] See CTIA's Semi-Annual Wireless Industry Survey, 2003.

[28] RCR Wireless News, a trade publication, collects information on cellular penetration rates by market. Unfortunately, this information is only available for the largest 50 markets. As a robustness check, future drafts of this paper will analyze cellular menus in these markets only, controlling for changes in the markets' cellular subscribers over the sample period.

the market, and the market's demographic attributes. Table 5 describes each of the variables in detail.

Results

To determine how entry affects the choice of tariff variety by cellular incumbents we take advantage of the difference in number of entrants across geographic markets. Figure 4 summarizes the change in the number of plans offered by the cellular incumbents in each market by number of entrants. We illustrate the response in plan offerings separately for providers that offer both analog and digital plans, for providers that have fully upgraded to digital service, and those that have not yet introduced any digital service. The figure shows a nearly identical, increasing relationship between the number of PCS entrants and the average number of digital calling plans offered by digital-only carriers and "mixed" providers that offer both types of plans. The relationship is non-monotonic in that the number of digital calling plans introduced initially falls as we move from markets with no PCS entrants to markets with one entrant, before then increasing in the number of entrants. The figure masks, however, that there are only five markets that do not experience any entry by 1998. The data show a similar pattern for analog-only providers. On average, providers increase the number of plans and increase them more in markets that experience more entry. For providers that offer both types of service, the data show a negative correlation between the number of PCS entrants into a market and the change in the number of analog calling plans offered. This reflects not only the effect of entry, however, but also that such carriers are in the process of phasing out analog service in lieu of digital service.[29]

[29] Note that subsequent to 1998, we do not observe a decline in the number of calling plans that are offered by wireless providers, which would indicate that any changes that we observe between 1996 and 1998 are only a temporary response to the new competitive environment. Instead, data for 1999 through 2002 indicates that wireless providers offer approximately 5.4 plans per plan group and significantly increase the total number of plans offered to on average 15.1 per provider as providers differentiate service increasingly by coverage area (local, regional, and national).

To control for differences in the market's population or other demographic characteristics that might affect the carriers' incentives to change their plan offerings, we analyze the effect of entry more formally by estimating the following regression:

$$\begin{aligned}\Delta Plans_{imt} &= \alpha + \beta_1 Prov\_Tech_{im} + \beta_2 Plan\_Type_{mt} \\ &\quad + \beta_3 \left(Prov\_Tech_{im}\right)\left(Plan\_Type_{mt}\right)\left(Entrants_m\right) + \gamma\, Z_{im} + \varepsilon_{imt}\end{aligned} \qquad \textbf{(10)}$$

where $\Delta Plans_{imt}$ is the change in the number of plans between 1996 and 1998 for incumbent *i* in market *m* for technology *t*, $Prov\_Tech_{im}$ is a dummy variable indicating whether incumbent *i* offers analog-only, digital-only or mixed technologies in market *m* in 1998, $Plan\_Type_{mt}$ indicates whether the plans' technology *t* in market *m* is analog or digital, $Entrants_m$ is the number of PCS entrants in market *m* between 1996 and 1998, and Z_{im} is a vector of control variables for incumbent *i* and market *m*. The interaction variable between provider technology, plan type, and number of entrants isolates the effect of entry on the incumbents' choices of number of plans by technology. Table 6 displays the results of different specifications of this regression based on linear regression techniques. The standard errors in the table have been adjusted to account for non-random clustering in the data since we observe some carriers in more than one market.

Specification I controls for market demographics that might affect incumbents' choice of number of plans and uses incumbent fixed-effects to control for firm-specific differences in the response to entry. It treats entry as exogenous, consistent with our hypothesis that entry is primarily determined by governmental policy. Under this assumption, we find that entry has a significant effect on the change in the number of plans offered by incumbent providers for both analog-only providers and mixed-technology providers. An additional entrant in a market with a mixed-technology provider is associated with an average decrease of 0.38 in the number of analog plans and an increase of 0.49 in the number of digital plans. Incumbents thus phase out more analog plans and introduce more digital plans in markets where they face more entrants. The effect is also economically significant given that the mean number of plans in a market is approximately six and the mean number of entrants in a market is over two. Similar to the digital portfolios of mixed-technology providers, we find that analog-only incumbents increase the number of plans offered by 0.44 for each additional entrant. The effect of entry on digital-only incumbents is positive but not significant. This coefficient is difficult to estimate precisely since the instances in which a carrier offers only digital service in a market are rare – only 15 of the 306 observations in our sample. Overall, these results are consistent with incumbents increasing tariff variety in markets where they face more competition. At the same time, incumbents also phase out tariffs for obsolete technologies more heavily in markets with more competitors.

We include measures of heterogeneity in demand within the market to reflect that carriers may base the introduction of new calling plans on the heterogeneity in consumer tastes. None of the heterogeneity measures has a significant effect on the change in the incumbents' tariff portfolio. As a robustness check, we also estimated the model using levels of the demographic variables. The results do not differ significantly from those discussed here, and as in the case of the heterogeneity measures, levels do not significantly affect the change in the number of plans offered by a provider.

To control for the possibility of endogenous entry into markets that are more attractive in unobservable ways, we use two-stage least squares techniques to re-estimate equation (10) under two specifications. In both specifications, we explain the possibly endogenous entry variable based on the instruments discussed above, including the area and population of the city, its degree of urbanization, the city's elevation and the standard deviation of its elevation. The first-stage regression has an adjusted R^2 of 0.42 indicating that the instruments are reasonably predictive of the timing of entry. Specification II in Table 6 replicates the earlier results. Most coefficients are similar in sign and magnitude; however, we estimate less precise coefficients than before. Entry continues to be associated with the introduction of additional calling plans in digital calling families by either digital-only or mixed technology providers, although the effect is only significant for the mixed providers. Similarly, we again find that analog offerings by mixed providers are reduced significantly in markets with more entry. It is only the effect of entry on plan offerings by analog incumbents that changes in sign relative to the OLS regression. An additional entrant reduces the number of plans offered by analog incumbents by 0.46 plans, although the effect is not significant. This is the main effect of instrumenting, which implies that there are omitted variables associated with both additional entry and reduced plan offerings in analog-only markets. One possible factor is growth in cellular demand in a market, which we are unable to measure, that would attract entry and, at the same time, place constraints on the existing analog capacity of incumbents, inducing them to phase out analog plans.

Our theoretical model predicts that a higher fixed cost of offering a plan should counter strategic incentives to offer a broader portfolio of calling plans in response to entry. To test this, we gather data on acquisition of radio advertising time across markets to proxy for marketing costs. With greater marketing costs per tariff (the K in our model), the fixed cost of offering an additional tariff is more difficult to recover and is increasingly difficult with a greater number of competitors. The third specification in Table 6 includes the marketing cost variable interacted with the instrumented number of entrants in the market to determine its effect on the change in the number of plans offered by firms in that market. We allow for a differential effect of marketing expenditures on analog portfolios offered by mixed-technology providers since the mixed-technology providers have already begun to phase out the analog calling families and may no longer be promoting them actively.

The results provide only weak evidence for the importance of fixed costs in driving the introduction or elimination of calling plans. Given the ongoing transition to digital service by mixed technology providers and the sunk nature of marketing costs, we do not have a prior expectation of how marketing costs will affect these plan families. We find that higher marketing expenditures significantly limit the introduction of these calling plans but that the effect is significantly attenuated with more entry. In a market with no entrants and evaluated at the means of the variables, a 10 percent increase in radio marketing costs is associated with 0.2 fewer analog plans being offered by mixed providers. In a market with four entrants, an increase in radio marketing costs is associated with no net change in the number of analog calling plans offered by mixed providers. For digital plans and analog plans offered in analog-only markets, the results are consistent with the predictions of our theoretical model but are not significant. A 10 percent increase in radio marketing costs with no entry is associated with 0.022 fewer plans being offered in these markets and the effect is reinforced by increased entry so that a market with four entrants is associated with 0.078 fewer plans. The insignificance of these results may reflect that radio advertising costs are but one of the costs incurred when offering a new tariff. Alternatively, the results could also signal that fixed costs of offering additional tariffs are not very significant, which is consistent with the strategic effect dominating the cost effect.

Since the variables that measure plan change and number of entrants are discrete, we estimate an ordered probit version of both equations. We simultaneously estimate the plan choice and instrumenting equation to allow for correlation in the errors between the two. We implement this using a Generalized Method of Moments (GMM) estimator. We assess parameter significance using a bootstrap sample of 200 replications and control for non-random clustering of unobservables by firm.[30]

The estimated coefficients and marginal effects of this model, including the marketing costs variables (the equivalent of Specification III in Table 6), are shown as Specification I in Table 7. The results are similar to the 2SLS results in Table 6 although the coefficients are in general slightly less significant. As in the 2SLS results, incumbents in both single and mixed-technology markets with more entrants reduce the number of analog plans more than incumbents in markets with fewer entrants, although the magnitude of the change is greater in the single technology market and less in the mixed technology markets. The results again suggest that incumbents in markets with more entrants introduced more digital plans than in markets with fewer entrants although the magnitudes are much greater here. Only two demographics variables are mildly

[30] The bootstrap procedure recognizes the clustering in the data. We first create a list of firms in our sample. For each iteration of the bootstrap procedure, we draw a firm from this list and use observations from all of the markets in which the firm operates in that iteration's data set. We keep adding randomly-drawn firms to the dataset until the number of plan/company/market observations is equal to or just exceeds the number of observations in the actual data set and the bootstrap sample contains at least one observation for each level of the plan change and entry variables.

significant; a market's population has a positive effect on the number of plans offered but is significant only at the 18% level, while commuting time also has a positive effect at the 14% level. The marketing variables here have similar effects to those found in the 2SLS estimation, but are not as significant. In a market with no entrants and evaluated at the means of the variables, a 10 percent increase in radio marketing costs is associated with 0.13 fewer analog plans being offered by mixed providers. In an identical market with four entrants, the same 10 percent increase in radio marketing costs is associated with 0.014 fewer analog calling plans being offered. As with the 2SLS estimates, for digital plans and analog plans offered in analog-only markets, the results are consistent with the predictions of our theoretical model but are not significant. A 10 percent increase in a market with four entrants is associated with 0.052 fewer plans.

The results in Table 6 are conditional on the technology choice made by the incumbents in each market. Our data can also inform the importance of entry in driving the incumbents' technology adoption choices. Consequently, we estimate an alternative, seemingly unrelated regression model that specifies the incumbents' technology adoption choices and their plan offering choices jointly as a system of equations, both of which are affected by entry. At the same time, we explicitly incorporate the discrete outcome data that we observe for the change in the number of calling plans and the number of entrants. We specify both the first-stage entry equation and the second stage plan offering equation as ordered probit models and the technology adoption equation as a binary probit:

$$\begin{aligned} \Delta Plans_{imt} &= \alpha^1 + \beta_1^1 \text{Prov\_}Tech_{im} + \beta_2^1 Plan\_Type_{mt} \\ &\quad + \beta_3^1 \left(\text{Prov\_}Tech_{im}\right)\left(Plan\_Type_{mt}\right)\left(Entrants_m\right) + \gamma^1\ Z_{im}^1 + \varepsilon_{imt}^1 \\ I_{im} &= \alpha^2 + \beta_1^2 Entrants_m + \gamma^2\ Z_{im}^2 + \varepsilon_{im}^2 \\ Entrants_m &= \alpha^3 + \gamma^3\ Z_{im}^3 + \varepsilon_{im}^3 \end{aligned} \quad \textbf{(11)}$$

where I_{im} is an indicator variable equal to one if firm *i* has implemented the digital technology in market *m* by 1998 and zero otherwise, Z_{im}^1, Z_{im}^2 and Z_{im}^3 are vectors of control variables for incumbent *i* and market *m*. ε_{im}^2 is a normal error term that gives rise to a probit model for the technology adoption equation, while ε_{im}^1 and ε_{im}^3 are normal error terms that give rise to ordered probit models for the plan change and entry equations. We use the same instrumental variables to control for the possible endogeneity of the number of entrants as in the linear calling plan regressions. We employ a GMM estimator to estimate the system of equations with an ordered probit first-stage estimation of the entry equation again allowing for potential correlation of errors across equations.

Specification II of Table 7 displays both the estimated coefficients and marginal effects from this model. We use bootstrap techniques based on 200 replications to assess parameter significance and control for non-random clustering of errors by firm. The digital technology adoption decision equation shows that amount of entry has a highly significant and positive effect on the likelihood of adopting the new technology. The effect is also economically significant. Each additional entrant increases the probability of adopting the new technology by 13 percent. The demographic and firm scope variables are in general not significant. The only significant effect is that firms in markets with higher consumer incomes are more likely to adopt the new technology.

The results for the plan change equation are similar to those obtained in Specification I of Table 7 although the magnitudes of the effects are somewhat different. As before, the results imply that mixed providers in markets with more entry eliminate more analog plans and introduced more digital plans than mixed providers in markets with less entry, however, the marginal effect of entry on tariff variety is approximately half the previous amount. The effect on digital plan introductions by mixed providers is very significant while the effect on analog plans is significant only at the 17% level. Entry induces firms that completely transitioned to the digital technology prior to 1998 to introduce additional plans, however the effect is not statistically significant. Finally, we find a statistically very significant, negative effect of additional entry on the change in the number of plans offered by firms who remain with the old analog technology. This may be a sign that such carriers, while not yet having explicitly introduced digital service, are anticipating its introduction by slowly phasing out plans on the old technology. The only control variable that is moderately significant is that for small geographic scope of the firm, significant at the 16% level.

Conclusion

Overall, our results are consistent with higher concentration being associated with fewer tariffs. Cellular incumbents expand the number of tariffs most in markets with more PCS entrants. This is consistent with cellular incumbents, when they faced only one other firm in 1996, having less incentive to undercut their competitors by introducing additional calling plans and incurring the fixed costs of administering multiple plans. With entry by PCS carriers between 1996 and 1998, the incumbents face more external competition and an increased incentive to "fill the tariff space" to steal customers whose tastes were not closely served by their existing menu of calling plans. This effect overwhelmed the incentive to avoid additional fixed costs.

We also find that entry indirectly affects plan offerings through its influence on technology adoption. Incumbents in markets with more competitors are more likely to transition from analog to digital transmission technologies and to more drastically phase out the old analog plans if they continued to promote both technologies.

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Table 1
Second Stage Equilibrium with Outside Good Price of 0.8
(p_0=0.8, P_0=0)

	Number of Firms in Market				
	2	**3**	**4**	**5**	**6**
Two Tariff Equilibrium					
Industry Profits	0.1375	0.1417	0.1427	0.1432	0.1435
Firm Profits	0.0687	0.0472	0.0357	0.0286	0.0239
Fraction Served	0.5152	0.5473	0.5555	0.5592	0.5613
Consumer Welfare	0.0449	0.0440	0.0438	0.0438	0.0437
Four Tariff Equilibrium					
Industry Profits	0.1384	0.1440	0.1455	0.1462	0.1466
Firm Profits	0.0692	0.0480	0.0364	0.0292	0.0244
Fraction Served	0.5213	0.5660	0.5787	0.5846	0.5880
Consumer Welfare	0.0447	0.0436	0.0434	0.0433	0.0433
Six Tariff Equilibrium					
Industry Profits	0.1384	0.1443	0.1460	0.1467	0.1472
Firm Profits	0.0692	0.0481	0.0365	0.0293	0.0245
Fraction Served	0.5216	0.5682	0.5824	0.5892	0.5931
Consumer Welfare	0.0447	0.0436	0.0433	0.0432	0.0432

Notes:
This table shows the total industry profits, per-firm profits, fraction of consumers served and total consumer welfare in the second stage of the theoretical model with different numbers of firms and tariffs. In computing the equilibria, we have set the price of the outside good to 0.8 and the fixed fee for the outside good to 0.

Table 2
Activation of PCS Systems in Top-100 CMAs by Launch Quarter
Fourth Quarter 1995 – Second Quarter 1998

Quarter of Launch	Number of Launches	Average Build-Out Time (Months)	Average Market Size
Q4-1995	2	11.0	3,538,229
Q1-1996	-	-	-
Q2-1996	2	13.0	1,062,081
Q3-1996	10	16.6	908,211
Q4-1996	27	20.2	2,106,664
Q1-1997	11	23.4	1,136,711
Q2-1997	26	26.0	2,031,952
Q3-1997	17	28.2	2,320,415
Q4-1997	23	30.0	2,099,855
Q1-1998	8	33.1	2,351,390
Q2-1998	22	26.8	1,900,680
Total	148	25.3	1,951,804

Source: *PCS Week* , various issues.

Table 3
Descriptive Statistics, Plan Characteristics

Plan Features, across Providers

		Fixed Fee			Included Peak Minutes		
		1996	1998	Change, 1996 to 1998	1996	1998	Change, 1996 to 1998
Analog Plans	Mean	77.31	72.06	5.25	229.85	301.05	71.20
	Std. Deviation	63.06	64.87	-1.81	343.91	470.98	127.07
	Minimum	9.95	9.95	0.00	0.00	0.00	0.00
	Maximum	449.95	592.99	-143.04	3000.00	3560.00	560.00
	Median	50.00	47.55	2.45	90.00	120.00	30.00
	# of Plans	1,145	1,017	-128	1,145	1,017	-128
Digital Plans	Mean		73.24			555.74	
	Std. Deviation		47.96			558.04	
	Minimum		14.95			0.00	
	Maximum		279.99			3000.00	
	Median		54.99			350.00	
	# of Plans		713			713	

Average Plan Features, within Provider

		Fixed Fee			Included Peak Minutes		
		1996	1998	Change, 1996 to 1998	1996	1998	Change, 1996 to 1998
Analog Plans	Mean	77.31	72.06	-5.25	229.85	301.05	71.20
	Std. Deviation	28.39	26.10	-2.29	151.22	195.82	44.60
	Minimum	24.99	18.99	-6.00	0.00	0.00	0.00
	Maximum	175.50	163.59	-11.91	625.00	1085.00	460.00
	Median	77.31	72.06	-5.25	229.85	301.05	71.20
	# of Plan Families	195	178	-17	195	178	-17
Digital Plans	Mean		73.24			555.74	
	Std. Deviation		15.34			198.41	
	Minimum		29.98			60.00	
	Maximum		114.99			1287.50	
	Median		71.74			517.14	
	# of Plan Families		132			132	

Table 4
Descriptive Statistics, 98 Largest Cellular Markets

Variable	Obser-vations	Mean	Standard Deviation	Min	Max
Number of Plans Offered in a Plan Group					
Analog Plan Groups, 1996	193	5.89	1.30	3.00	8.00
All Plans offered by Provider, 1998	193	8.69	3.25	3.00	17.00
Analog Plan Groups, if offered, 1998	178	5.78	1.73	1.00	10.00
Digital Plan Groups, if offered, 1998	128	5.06	1.58	2.00	9.00
Change in the Number Plans Offered, 1996-98					
All Plans offered by Provider	193	2.80	3.47	-5.00	12.00
Analog Plan Groups, if offered	178	-0.07	1.92	-6.00	5.00
Digital Plan Groups, if offered	128	5.06	1.58	2.00	9.00
Plan Group Characteristics, 1998					
Percent of Analog Plan Groups	306	0.58	0.49	0.00	1.00
Percent of Digital Plan Groups	306	0.42	0.49	0.00	1.00
Providers' Technology Choice by Market, 1998					
Percent of Analog Only Providers[1]	193	0.34	0.47	0.00	1.00
Percent of Digital Only Providers[1]	193	0.08	0.27	0.00	1.00
Percent of Mixed Technology Providers[1]	193	0.59	0.49	0.00	1.00
Number of Markets Present	24	12.75	15.59	1.00	48.00
Percent of Providers with Small Potential Network	24	0.63	0.49	0.00	1.00
Percent of Providers with Large Potential Network	24	0.21	0.41	0.00	1.00
Entrants per Market	98	2.17	1.08	0.00	4.00
Zero Entrants	98	0.05	0.22	0.00	1.00
One Entrant	98	0.26	0.44	0.00	1.00
Two Entrants	98	0.27	0.44	0.00	1.00
Three Entrants	98	0.33	0.47	0.00	1.00
Four Entrants	98	0.10	0.30	0.00	1.00
Market Characteristics					
Population (000)	98	1,524.66	1,662.93	175.20	9,519.34
Average Commuting Time (mins)	98	24.58	3.25	19.00	38.90
Household Income (000)	98	44.03	7.18	31.05	74.34
Percent with B.A. or more	98	24.41	5.43	13.09	41.66
Heterogeneity in Commuting Time	98	87.57	1.06	84.58	89.98
Heterogeneity in Income	98	92.46	0.23	91.68	93.09
Heterogeneity in Education	98	83.97	1.82	77.14	86.80
Radio Advertising Costs	90	58.6	63.44	11.00	393.00

Notes:

[1] The unit of observation is the market and provider, measuring the percent of providers that offer a given technology in the market, but not whether the provider offers analog, digital, or both technologies on its entire network across markets.

Table 5
Variable Description and Data Sources

Variable	Description	Data Source
Chg_Plans	Change in the number of plans offered by cellular incumbents in each market within a given technology (analog or digital).	Kagan World Media
Prov_Analog	Indicator variable: Provider offers analog service only in both 1996 and 1998	
Prov_Mixed	Indicator variable: Provider offers separate analog and digital plan choices in 1998	
Prov_Digital	Indicator variable: Provider offers digital service only in 1998	
Plans_Analog	Indicator variable: Plan group's technology is analog	
Plans_Digital	Indicator variable: Plan group's technology is digital	
Entrants	Number of PCS entrants into the market between 1996 and 1998	
Small Potential Network	Indicator variable: Provider offers cellular service in at most 5 of the top 100 cellular markets	
Large Potential Network	Indicator variable: Provider offers cellular service in more than 15 of the top 100 cellular markets	
Population	MSA population in thousands	Census 2000
Average Commuting Time	Average commuting time in minutes	
Household Income	Household income in thousands of dollars	
Percent with B.A. or more	Percent of the MSA population with at least a B.A.	
Heterogeneity in Communting Time	Heterogeneity index. Groups classify shares of workers with commuting time. Categories begin at 5, 10, 15, 20, 25, 30, 35, 40, 45, 60, and 90 minutes.	
Heterogeneity in Household Income	Heterogeneity index. Groups classify shares of households with income in thousands. Categories begin at $10, $15, $20, $25, $30, $35, $40, $45, $50, $60, $75, $100, $125, $150, $200.	
Heterogeneity in Educational Attainment	Heterogeneity index. Groups: shares of population 25 years and over with less than a 9th grade education; 9th-12th grade education; high school graduate or higher, no BA; bachelor's degree or higher.	
% City	Percent of the MSA area that is within the MSA's central cities.	
Radio Advertising Costs	Cost per rating point of men 18 and older for a 60-second spot in 1997.	Marketer's Guide to Media, 1998
Average Elevation	Elevation averaged across regular grid points in the MSA.	US Geological Survey
Std. Deviation of Elevation	Standard deviation in elevation at regular grid points in the MSA.	

The heterogeneity index for commuting time, household income and educational attainment is defined as:

$$\text{Heterogeneity Index} = 1 - \sum_i (group_i)^2$$

Table 6
Changes in the Menu of Plans offered by Cellular Incumbents, 1996-1998
Linear Instrumental Variables Model

		Instrumental Variables Regression	
	Specification I	Specification II	Specification III
Technologies offered by Provider in 1998			
Prov_Analog	-0.93740	0.20678	-0.77406
	(1.2215)	(1.9554)	(2.4033)
Prov_Mixed	0.44683	0.57089	0.20278
	(0.9887)	(1.4046)	(1.4501)
Plans' Type of Technology			
Plans_Digital	3.12103 ***	2.73147 ***	0.97560
	(.52212)	(0.7434)	(1.4038)
Entry by PCS Providers			
Prov_Analog*Entrants	0.44490 **	-0.45968	-0.88324
	(0.2264)	(0.5122)	(0.7081)
Prov_Digital*Entrants	0.39410	0.24824	0.14171
	(0.3991)	(0.5686)	(0.5673)
Prov_Mixed*Plans_Analog*Entrants	-0.38202 *	-0.68835 **	-1.34120 ***
	(0.2143)	(0.2994)	(0.4741)
Prov_Mixed*Plans_Digital*Entrants	0.49236 ***	0.33875 *	0.42440
	(0.1551)	(0.1870)	(0.4243)
Population	0.00002	0.00004	0.00037 **
	(0.0001)	(0.0001)	(0.0002)
Demand Heterogeneity Measures			
Commuting Time Index	-0.08965	0.01036	0.07399
	(0.1481)	(0.1685)	(0.2092)
Household Income Index	-0.71076	-0.50103	-0.73881 *
	(0.4342)	(0.3369)	(0.3812)
Educational Attainment Index	-0.01583	0.06050	0.11697
	(0.0757)	(0.0692)	(0.0866)
Marketing Costs			
Radio Ad Cost*Mixed_Analog			-0.03412 **
			(0.0154)
Radio Ad Cost*(1-Mixed_Analog)			-0.00377
			(0.0186)
Radio Ad Cost*Mixed_Analog*Entrants			0.00858 *
			(0.0048)
Radio Ad Cost*(1-Mixed_Analog)*Entrants			-0.00241
			(0.0062)
Included Fixed Effects	Provider	Provider	Provider
Observations	306	306	282
R-Squared / Adjusted R-Squared	0.7373	0.7302	0.7408

Dependent variable: change from 1996 to 1998 in the number of plans offered by technology. Clustered standard errors in parentheses. * = 10% significance, ** = 5% significance, *** = 1% significance. The variable Mixed_Analog equals Prov_Mixed*Plans_Analog. Specifications II and III are two-stage least squares regressions. The results from the first-stage regression, together with the corresponding standard errors in parentheses, are given by:

$$ENTRANTS = \underset{(0.0194)}{0.0908}\,POP - \underset{(0.0002)}{0.0008}\,POP^2 + \underset{(0.906)}{0.1031}\,AREA - \underset{(0.0023)}{0.0016}\,AREA^2 + \underset{(0.9562)}{0.4208}\,\%CITY - \underset{(0.3081)}{0.1408}\,ELEV\text{-}AVG - \underset{(1.1672)}{0.4416}\,ELEV\text{-}SD + \varepsilon$$

where *POP* denotes the 1999 CMA population, *AREA* the CMA's landarea, *%CITY* the percentage of the area that falls within the central cities of the CMA, and *ELEV-AVG* and *ELEV-SD* the average and standard deviation of the CMA's elevation, respectively. The first stage regression furthermore includes six region indicators.

Table 7
Changes in the Menu of Plans Offered by Cellular Incumbents, 1996 – 1998
GMM Estimation of Discrete Models

	Specification I			Specification II		
	Coefficient	95% Confiden-ce Interval	Marg. Effect	Coefficient	95% Confiden-ce Interval	Marg. Effect
Plan Change Equation						
Prov_Analog	2.23683	(-2.9314,6.3073)	2.68639	1.971096	(2.1769,5.0951)	2.58839
Prov_Mixed	0.38567	(-4.1563,2.6943)	0.46318	0.38525	(-3.1518,1.9465)	0.50590
Plans' Type of Technology						
Plans_Digital	0.34395	(-2.2123,15.4408)	0.41307	2.271562	(0.9222,3.6555)	2.98295
Entry by PCS Providers						
Prov_Analog*Entrants	-1.82050 **	(-3.060,-0.2791)	-2.18639	-0.94529 **	(-2.3813,-0.1576)	-1.24133
Prov_Digital*Entrants	0.57761	(-0.6346,1.6522)	0.69370	0.40206	(-1.0974,0.8451)	0.52797
Prov_Mixed* (Plans_Analog)*Entrants	-0.78317 *	(-2.4527,0.0133)	-0.94057	-0.23031	(-0.7244,0.1127)	-0.30244
Prov_Mixed* (Plans_Digital)*Entrants	0.84315 **	(0.0697,1.9549)	1.01261	0.50789 ***	(0.1391,0.7050)	0.66694
Population	0.00021	(-0.0005,0.0001)	0.00025	-0.00006	(-0.0001,0.0001)	-0.00008
Demand Heterogeneity						
Commuting Time Index	0.22325	(-0.4179,0.0506)	0.26812	0.05948	(-0.1979,0.1479)	-0.07811
Household Income Index	-0.35412	(-0.1705,0.8776)	-0.42529	-0.31953	(-0.6945,0.1347)	-0.41960
Edu. Attainment Index	0.14914	(-0.2557,0.1120)	0.17911	0.09183	(-0.0255,0.1659)	0.12059
Marketing Costs						
Radio Ad Cost*Mixed_Analog	-0.01848	(-0.0146,0.1476)	-0.02219			
Radio Ad Cost*(1-Mixed_Analog)	0.02238	(-0.0468,0.0068)	0.04348			
Radio Ad Cost* Mixed_Analog*Entrants	0.00414	(-0.0489,0.0322)	0.00497			
Radio Ad Cost* (1-Mixed_Analog)*Entrants	-0.01088	(-0.0086,0.0210)	-0.01307			
Digital Adoption Decision Equation						
Entrants				0.33838 ***	(0.1680,0.4457)	0.13128
Percent with B.A. or more				-0.01912	(-0.0601,0.0462)	-0.00742
Commuting Time				0.02738	(-0.0333,0.0675)	0.01062
Population				-0.00147	(-0.0054,0.0097)	-0.00057
Household Income				0.01130 *	(-0.0087,0.0412)	0.00438
Large Geographic Scope				0.550878	(-0.1467,0.5303)	0.21372
Small Geographic Scope				0.735686	(-0.1060,0.9237)	0.28542
Observations	281			306		

Provider fixed effects included in both plan change and digital adoption decision equations. Numbers in parentheses provide 95% confidence interval using the bootstrap percentile method. Provider fixed effects included. * = 10% significance, ** = 5% significance, *** = 1% significance. The plan change equation is estimated as an instrumented ordered Probit model. Specification II estimates the plan change equation as an instrumented ordered Probit model and the digital adoption equation as an instrumented Probit model in a seemingly unrelated regression (SUR) system of equations. The system is estimated via GMM using all exogenous variables and polynomial functions of the exogenous variables as instruments. The 95% confidence intervals are based on 200 bootstrap samples that account for non-random clustering of errors by firm. The estimated coefficients of the first stage entry equation, together with the corresponding 95% confidence interval based on the bootstrap percentile method in parenthese, are for Specification I:

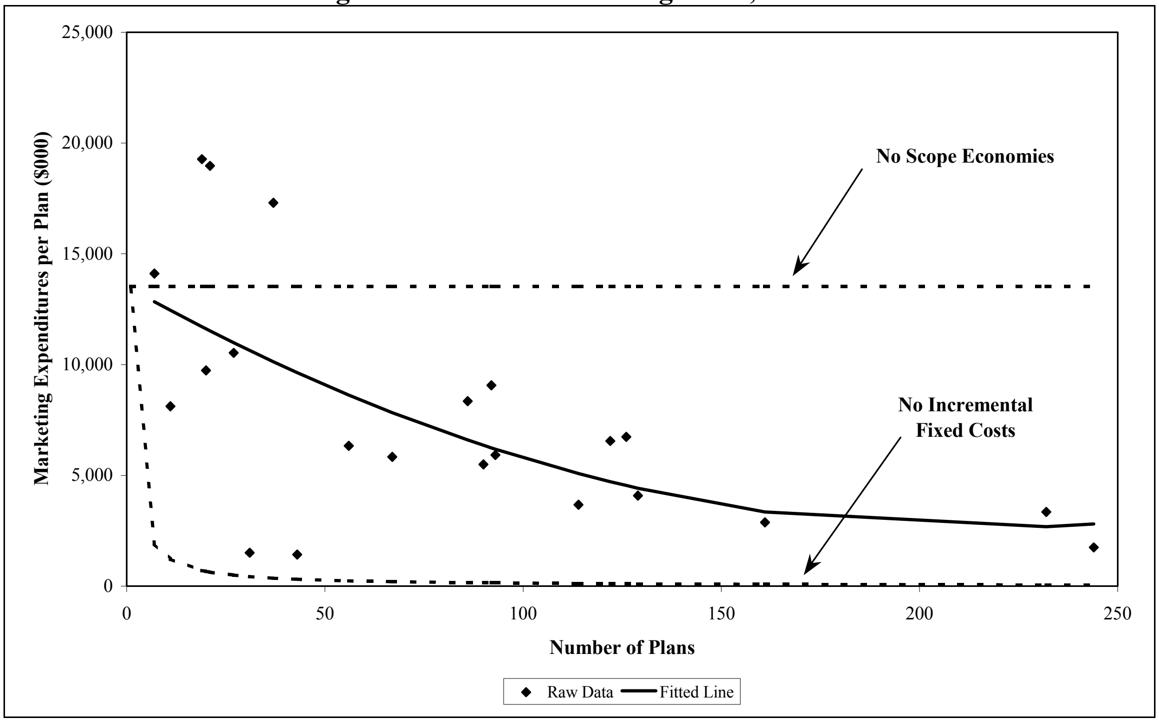
$$ENTRANTS = \underset{(0.1117,0.4264)}{0.1429}\, POP - \underset{(-0.0034,-0.0008)}{0.0013}\, POP^2 + \underset{(-0.4679,0.2553)}{0.1612}\, AREA - \underset{(-0.0015,0.0611)}{0.0007}\, AREA^2 + \underset{(-3.7549,1.4224)}{0.4091}\, \%CITY - \underset{(-1.2172,1.3708)}{0.1280}\, ELEV\text{-}AVG - \underset{(-2.7274,2.7280)}{1.2490}\, ELEV\text{-}SD + \varepsilon$$

and for Specification II:

$$ENTRANTS = \underset{(0.1059,0.2380)}{0.1408}\, POP - \underset{(-0.0021,-0.0009)}{0.0012}\, POP^2 + \underset{(-0.1422,0.3411)}{0.1803}\, AREA - \underset{(-0.0060,0.0338)}{0.0017}\, AREA^2 + \underset{(-1.4347,1.4984)}{0.4527}\, \%CITY - \underset{(-0.9244,1.1416)}{0.3134}\, ELEV\text{-}AVG - \underset{(-3.788,1.4116)}{1.0088}\, ELEV\text{-}SD + \varepsilon$$

where POP denotes the 1999 CMA population, AREA the CMA's landarea, %CITY the percentage of the area that falls within the central cities of the CMA, and ELEV-AVG and ELEV-SD the average and standard deviation of the CMA's elevation. The first stage regression furthermore includes six region indicators.

Figure 1
Marketing Cost Structure of Calling Plans, 1996 and 1998

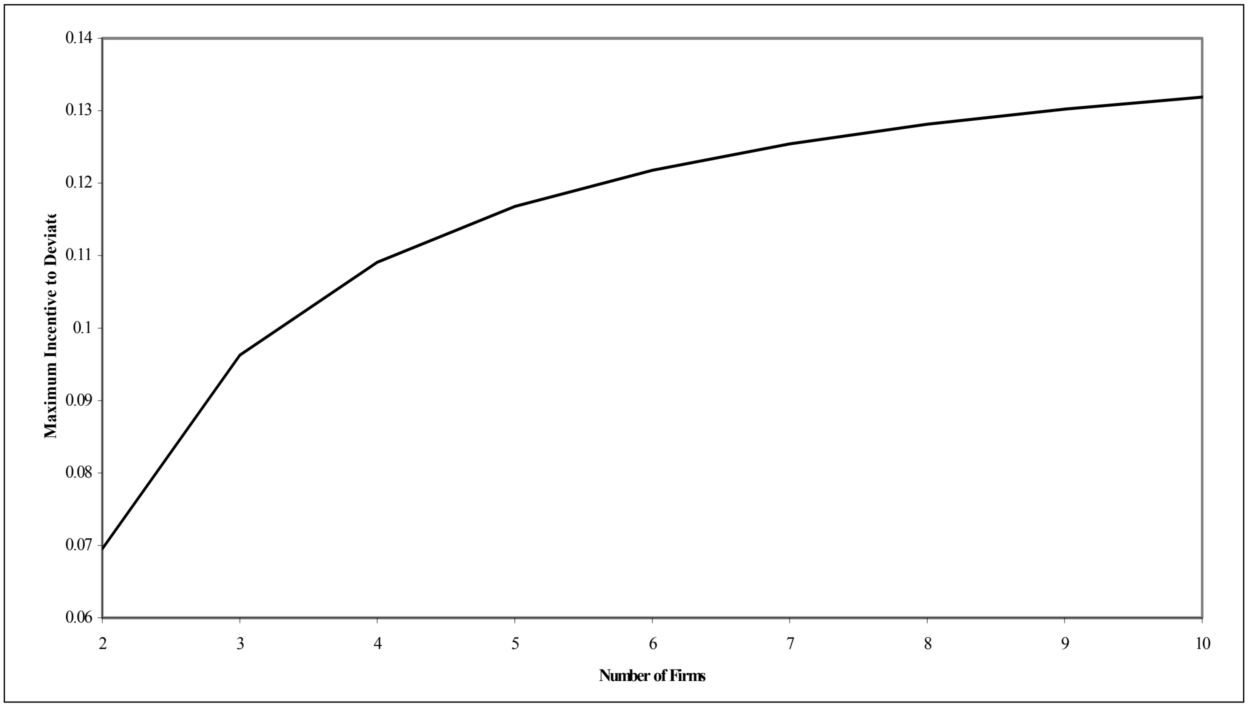


Source: Annual marketing expenditures are taken from "Mobile Metrics – Fall 1999," Salomon Smith Barney, September 10, 1999. Data are for Airtouch, ALLTEL, Ameritech, AT&T, Bell Atlantic, BellSouth, Century Telephone, Comcast Corporation, GTE Corporation, SBC Communications, and United States Cellular for 1996 and 1998.

The fitted line represents the predicted values from the regression:

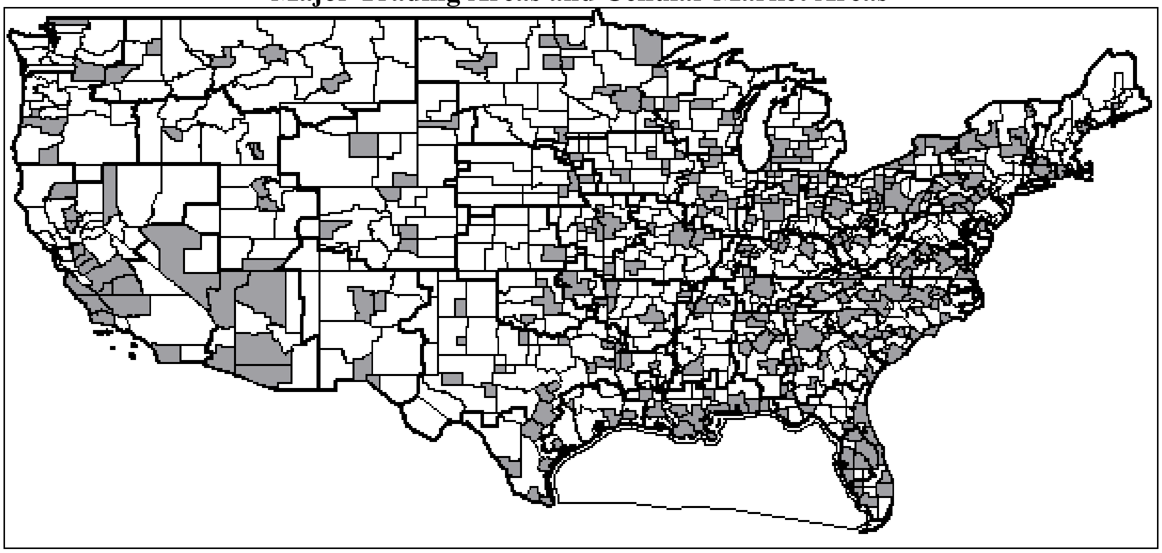
$$\text{E}[\textit{Marketing Expenditures Per Plan}] = 13{,}533.81 - 100.61\textit{Plans} + 0.23\textit{Plans}^2.$$

Figure 2
Gains From Deviation: Two versus Three Plans



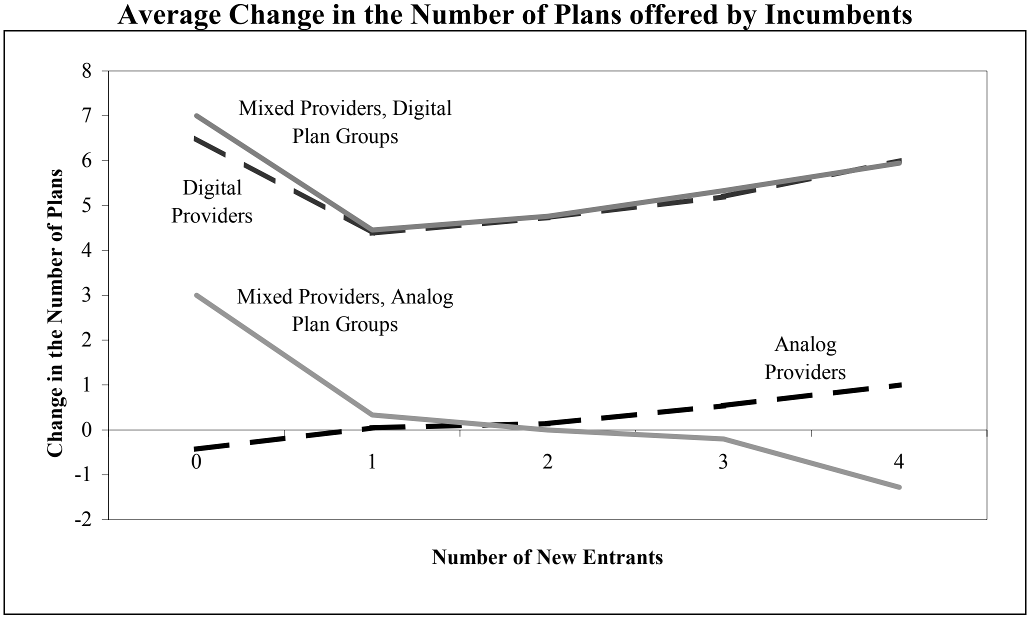
The figure shows the maximum additional profits an oligopolist can obtain by deviating from offering two tariffs to offering three tariffs in the theoretical model as a function of the number of firms in the market. The maximum deviation is defined as the profits the oligopolist could obtain if it slightly undercut each of its competitors' two tariffs by offering three tariffs. In computing the equilibria, we have set the price of the outside good to 0.8 and the fixed fee for the outside good to 0.

Figure 3
Major Trading Areas and Cellular Market Areas



This map shows the geographic market areas for cellular service. The dark bordered regions are the 51 MTAs and the light-bordered areas are the CMAs.

Figure 4
Average Change in the Number of Plans offered by Incumbents



This graph displays the relationship between the average change in the number of plans in a market and the number of entrants in a market for four different plan family/provider types: digital plans offered by mixed providers, digital plans offered by digital-only providers, analog plans offered by mixed providers and analog plans offered by analog-only providers.