

# The Limited Gains From Complex Tariffs<sup>\*</sup>

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## Abstract

This paper uses an equilibrium model of multipart nonlinear pricing to determine the magnitude of foregone profits due to the implementation of simple tariff options. I then use the available information from a cross-section of independent cellular telephone markets to study how these foregone profits vary with markets' observable characteristics. Results show that commercialization costs effectively limit the number of tariff options offered to consumers. The evidence presented in this paper suggests that firms should only offer a few tariff options if their commercialization and product development costs are non-negligible. More importantly, this evidence favors the use of two-part tariffs and other simple pricing strategies in theoretical modeling in order to overcome the analytical difficulties of the existing general models of nonlinear pricing and thus responds to the many open questions in the area of nonlinear pricing.

**Keywords:** Multipart Tariffs; Approximately Optimal Screening; Foregone Profits.

**JEL Codes:** C39, D43, L96

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# 1 Introduction

Over the past thirty years, the theory of nonlinear pricing has grown to become a well-established area of economics differentiated from other applications of asymmetric information and mechanism design. The basic idea behind these models is that the existence of heterogeneous consumers allows firms to increase their profits by engaging in incentive-based price discrimination. According to the common interpretation of the *Second Degree Price Discrimination* paradigm of Pigou (1932), consumers' individual valuations remain private information and the seller only knows the population distribution of these valuations. In such an environment, a monopolist may maximize his expected profits through the design of a nonlinear tariff in an attempt to extract most informational rent from consumers while minimizing agents' individual incentives to deviate from their optimal consumption.

The solution to this problem is well-known.<sup>1</sup> The optimal tariff is a fully nonlinear function of purchases that solves a complex variational problem defined by the preferences of consumers and the distribution of types. Under very general conditions, the optimal nonlinear tariff is a concave function leading to quantity discounts, *i.e.*, high-valuation (large) customers are offered a lower price per unit than low-valuation (small) consumers. By pricing large customers closer to marginal costs, nonlinear pricing enhances welfare while at the same time extracting sufficient rents from all consumers to cover potential fixed costs of production and/or distribution. This may explain why nonlinear pricing is commonly used in industries in which fixed or sunk costs are important but the costs of monitoring consumption are low, such as in electricity, water, gas, telecommunications, and cable television industries.

Despite their popularity in academic journals and advanced economics textbooks, fully nonlinear tariffs are rarely implemented as such but rather through a menu of self-selecting tariff options generally consisting of a fixed fee plus a constant charge per unit of usage. Economists are well aware of this divorce between theory and the practice of price discrimination,<sup>2</sup> but this disconnection between theory and common pricing practice has failed to (i) make theorists reconsider the use of complicated pricing mechanisms, and (ii) attract any attention from applied economists to measure the loss of rents that follows the implementation of approximately optimal tariffs. This paper is the first attempt to remedy the lack of empirical measurements on this matter. Results should encourage theorists to justify the use of simple pricing mechanism than fully nonlinear tariffs as an effective way to advance our knowledge on many of the remaining open questions in this area, such as optimal multiproduct bundling, multidimensional pricing, and competitive nonlinear tariffs.

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<sup>1</sup> Goldman, Leland, and Sibley (1984), Guesnerie and Laffont (1984), Mussa and Rosen (1978), and Maskin and Riley (1984) are the classic references in this literature. Tirole (1989, §3) and Wilson (1993, Part I) present the solution to this problem in detail and include further references on this topic.

<sup>2</sup> See for instance Gasmi, Laffont, and Sharkey (1999, p.91), Milgrom and Roberts (1992, p.216), or Schmalensee (1989, p.418).

From a theoretical perspective, or even from a behavioral one, it could be argued that firms do not behave optimally when they make use of a few simple tariff options to screen consumers. The work of Faulhaber and Panzar (1977) first showed that profits are monotonically increasing in the number of self-selecting two-part tariffs while Wilson (1993, §8.3) proved that profits increase at a decreasing rate, *i.e.*, that the foregone profits of implementing a nonlinear tariff by means of an optimally designed piecewise linear approximation decrease very rapidly with the number of tariff options offered. This is quite a general result that holds for any well-behaved preferences fulfilling the well-known *single-crossing* property (SCP) and for any “sufficiently smooth” distribution of types, *i.e.*, a continuous univariate distribution with the *increasing hazard rate* property (IHR).

Does all this mean that firms do not maximize profits on a regular basis when they offer only a few tariff options? One answer to circumvent this apparent inconsistency with the assumed optimizing behavior of firms is to conclude that the distribution of consumer types is defined on a discrete set. This is the case of Crawford and Shum (2007), in which they analyze consumers’ choices among a few bundles of cable television packages. Contrary to the cable industry, cellular telephone usage is rather continuous and not only defined around a few given number of monthly minutes of usage. Thus, the distribution of consumer types needs to be defined on a compact support. The approach adopted in the present paper is to assume that there are some costs associated with the commercialization of each tariff plan. If foregone profits decrease rapidly with the number of tariff options available to consumers, the mere existence of some commercialization or development costs associated with each tariff option rationalizes firms’ behavior to only offer a discrete number of options. Whether these costs are due to training of the sales force or feared revenue losses due to consumers’ aversion to complexity is a secondary matter beyond the scope of the present research. If a firm offers  $n$  tariff options, the suggested empirical framework of this paper provides with an interval estimate of these *marketing costs* associated with the foregone incremental profits of offering either  $n + 1$  instead of  $n$  or  $n$  instead of  $n - 1$  tariff plans.

This paper develops and estimates an equilibrium model of multipart tariffs suitable for evaluating the magnitude of foregone profits associated with offering a finite number of tariff options. The paper uses data on pricing strategies of telephone carriers in the early U.S. cellular telephone industry. This is the first attempt to use data from a particular industry (instead of just numerical examples) to evaluate the actual foregone rents from offering only a few tariff options. The empirical analysis makes use of detailed tariff information together with a measure of market penetration and average-paid bill. Since individual consumption data are not available the empirical analysis makes use of flexible functional forms for demand and the distribution of consumer types in order to identify the relevant parameters from the position of the tariff options. The analysis focuses on the monopoly period of these early markets in order to avoid having to deal with the strategic considerations of nonlinear pricing competition.

The empirical analysis is conducted in three stages. I first use an equilibrium model of multipart nonlinear pricing for the actual number of self-selecting two-part tariffs observed in each market-time combination. These particular equilibrium conditions are then used to recover the relevant structural parameters of the model. They include the indexing parameter of the distribution of asymmetric information, the slope of demand, consumers' maximum willingness to pay, as well as firms' marginal costs and the share of active consumers. This approach allows me to obtain price-independent indicators of the informational features of each market taking the pricing behavior of local cellular monopolies as optimal. The advantage of this approach is that it makes use of commonly available data —firms' tariff schedules— to summarize the relevant informational features of the market. In particular, this approach is quite useful for the identification of the unknown distribution of consumer types from equilibrium conditions that assume that firms are aware of the heterogeneity of their customer base and price the service accordingly.

The second stage of the empirical analysis addresses the estimation of the distribution of foregone profits due to approximate screening. Once the structural parameters of the model are independently estimated for each market-time observation, the optimal, fully nonlinear tariff and multipart tariffs with different numbers of options can also be computed. It is then possible to evaluate the share of total expected profits secured by a particular number of tariff options and the bounds of the estimate of the *marketing costs* that help to explain the approximate screening mechanism employed in each market-time case. Since all these variables are computed for every market-time combination in the sample, I therefore recover the empirical distribution of the efficiency loss indices and foregone earnings of each pricing strategy actually put in place across markets.

Finally, at the third stage of the empirical analysis I study the distribution of foregone earnings, conditioning on exogenous and observable firm and market characteristics. This last econometric analysis makes use of the cross-section variation of pricing across markets to illustrate how these foregone profits are related to observable market characteristics. Since the size of foregone profits is heavily dependent on the number of tariff options actually offered, I simultaneously analyze how expected profits and marketing costs influence the decision to offer more or fewer options. Thus, the equilibrium model helps recover the value of structural parameters behind unobservable variables such as the distribution of consumer types, marginal costs, or *marketing costs*, and the cross-market variation in the data allows us to learn how exogenous observable variables influence the size of foregone profits associated with approximately optimal screening, as well as the number of tariff options offered.

## 1.1 Main Results

The evidence supports the hypothesis that small unobserved *product development costs* prompt firms to offer a few tariff options to screen consumers, at least in early markets like the one studied in this paper, which

is characterized by a relative abundance of low-valuation customers. Although, on average, a firm in the sample that offers only a two-part tariff gives up 35 cents per month per potential customer for not offering a second tariff option, these average foregone profits of price discrimination plunge to 7 cents per month per individual for the same firm if it offers just three tariff options. Adding tariff complexity beyond two or three options does not seem to pay much.

Perhaps a more striking result is that these foregone profits associated with simple two-part tariffs represent, on average, a profit loss of only 3% relative to the expected profit level under a fully nonlinear tariff in the absence of screening costs. This result is representative of situations, like the early U.S. cellular telephone industry, in which—as the estimates presented in this paper show—large customers are less common than small ones. In such situations discrimination works by excluding low-valuation customers rather than inducing different optimal behavior among many, mostly identical, low-valuation consumers.

While existing simulations commonly assume a uniform distribution of consumer types, the calculations of this paper make use of market-specific estimated distributions that systematically put more probability mass on low-valuation customers. Therefore, the reported share of maximum profits secured under different pricing strategies always exceeds existing estimates. Thus, for instance, a simple flat tariff achieves between 57% and 79% of the expected profits of fully nonlinear pricing (depending on whether the firm offered one or three options) while linear pricing secures between 91% and 94%, a larger percentage than the numerical simulations of Gasmi et al. (1999). Similarly, a single two-part tariff secures about 97% of the profits of a fully nonlinear tariff, a far larger percentage than the 75% of Rogerson (2003) and the 89% of Wilson (1993, §6.4). When monopolists offer two tariff options they secure over 99% of maximum profits, well above the 74% mark of Chu and Sappington (2007).

## 1.2 Literature Review

Many of the papers dealing with the performance of pricing mechanisms antedate the developments that established nonlinear pricing as a major application of game theoretical models of asymmetric information. Thus, the questions addressed by this early literature deal with ensuring participation and with distribution effects rather than performance of the different pricing mechanisms.<sup>3</sup> Wilson (1993, §6.4) first addresses the case of multipart tariffs and computes several numerical examples to illustrate how rapidly a few tariff options can approximate the results of a fully nonlinear tariff. His main conclusion is that very simple pricing mechanisms generate a substantial fraction of the total expected profits under nonlinear pricing, and furthermore, foregone profits decrease rapidly with the number of tariff options offered.

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<sup>3</sup> See the works by Auerbach and Pellechio (1978), Dimopoulos (1981), Murphy (1977), and Schmalense (1981).

Two recent papers in the area of procurement have revisited this result. Rogerson (2003) shows that a two-item *Fixed Price Cost Reimbursement* (the equivalent of a two-part tariff) performs better than a *Fixed Price Contract* (a flat tariff) singled out by Gasmi et al. (1999) when marginal costs (types) are uniformly distributed. Still, all results critically depend on particular functional form assumptions to compute the foregone rents and Chu and Sappington (2007) show how critical such assumptions are in selecting the simplified cost-sharing contract that secures the largest share of the maximum expected rents. It is the concern of Chu and Sappington (2007) that best justifies the present approach. I rely on flexible functional forms to estimate the money value of these foregone rents. Instead of selecting arbitrary values for the parameters I identify them through the profit maximizing equilibrium conditions of the particular number of tariff options offered in each market. The approach of this paper might thus also be applied to evaluate the expected revenues from using specific procurement contracts. Starting from actual data rather than only using numerical simulations better compares the potential returns associated with each type of incentive contract.

There are some empirical papers that have also used tariff information to study related features of nonlinear pricing. Among reduced form studies, Busse (2000) addresses how firms might use tariff features to collude in the presence of multimarket contact, Busse and Rysman (2005) analyze how the shape of nonlinear tariffs varies with competition among firms, Miravete (2007b) shows that entry not only simplifies the tariffs offered by competing firms, but also that deceptive pricing strategies become less common, and Seim and Viard (2006) document the effect that entry of new competitors has on innovation and the number of tariff options offered by competing firms. Among those papers using structural methods, Basaluzzo and Miravete (2007) evaluate a model of multidimensional screening in cellular telephony, Crawford and Shum (2007) estimate a structural model of nonlinear quality discrimination in the cable industry, Lambrecht, Seim, and Skiera (2007) estimate the demand for internet services when the service is priced with a three-part tariff, Leslie (2004) evaluates the incremental profits of introducing new quality categories in the pricing of a Broadway theater, Miravete (2005) evaluates the expected welfare performance of alternative sequential screening mechanisms using optional tariffs and individual consumption of local telephone service in Kentucky, while Narayanan, Chintagunta, and Miravete (2007) estimate a continuous/discrete model of tariff choice and local telephone usage allowing for consumer uncertainty of future demand as well as individual learning.

### 1.3 Outline

Section 2 presents a single-dimensional nonlinear pricing model and describes how to recover its basic structural elements when the optimal tariff is implemented by a menu of self-selecting two-part tariffs, including the underlying *marketing or commercialization* costs that rationalize the offering of only a few

tariff options. Section 3 overviews the features of the early U.S. cellular telephone industry. Section 4 first describes the empirical strategy of the paper and shows how the particular formulation of the single-dimensional nonlinear pricing model helps to identify the structural parameters of the model. Then it reports the estimates of the structural parameters for different market-time pairs. After recovering these parameters, it presents the estimates of the foregone profits, their relative size relative to the fully nonlinear solution, and finally the interval estimates of *marketing costs* in each market. Finally, this section also conducts a simple econometric analysis to describe how these foregone rents vary with market-specific observable characteristics conditional on the actual number of effective tariff options offered. Section 5 concludes.

## 2 An Equilibrium Model of Optional Tariff Plans

This section presents an equilibrium model of nonlinear tariff in which a monopolist discriminates among heterogeneous customers by means of a discrete number of self-selecting tariff options. In order to capture the most relevant institutional features of the cellular industry, the model combines the following elements:

1. Usage intensity is substantially diverse across potential customers. Consumers' preferences can be described by the utility function  $U(x, \theta)$ , which is at least twice continuously differentiable, increasing and concave in monthly telephone usage denoted by  $x$ , increasing in the preference parameter  $\theta$ , and strictly concave in  $(x, \theta)$ .
2. Despite some large telephone bills, cellular telephony normally represents a small fraction of the revenues of consumers. Thus, assuming away income effects, consumer surplus for consumer of type  $\theta$  can simply be computed as the integral of the demand function of this individual above market price  $p$ . Therefore, the corresponding direct demand function  $x(p, \theta)$  is such that  $U_x(x, \theta) = p$ . Demand is downward slopping,  $x_p(p, \theta) < 0$ , and such that  $x_\theta(p, \theta) > 0$ , following the concavity of the utility function in  $(x, \theta)$ . This latest condition is the well-known *single-crossing* property (SCP) that ensures that the demand of different consumers can unequivocally be ranked with respect to the type index  $\theta$  and independently of the marginal tariff rate  $p$ .
3. Cellular telephone usage is continuous rather than concentrated around a few levels of monthly usage, and thus it is appropriate to assume that consumers heterogeneity can be represented by  $\theta$ , a single dimensional preference index with a continuously differentiable probability density function  $f(\theta)$  defined on the compact support  $\Theta = [\underline{\theta}, \bar{\theta}]$ . In addition to SCP a sufficient condition to obtain a well-behaved tariff solution is that the hazard rate of the distribution of consumer types is increasing (IHR), i.e.,  $h'(\theta) > 0$ , where  $h(\theta) = f(\theta)/[1 - F(\theta)]$ .

4. In the early U.S. cellular industry only few out of many potential customers actually subscribed to the service. Instead of assuming full coverage, the model needs to determine the lowest active type  $\theta_1$  that is indifferent between participating in the market or not, *i.e.*,  $U(\theta_1) = \underline{U} = 0$  so that the set of active consumers is given by  $\{\theta | \theta > \theta_1\}$  and the market share of active consumers is  $1 - F(\theta_1)$ .
5. Telecommunications are characterized by a high fixed cost and much smaller marginal cost. I thus will assume a constant returns to scale technology.
6. Since cellular carriers did not change tariffs frequently, I assume that firms solve independent static problems of nonlinear pricing in the first and last quarter of the monopoly phase of each market.
7. The model does not allow for the existence of network externalities because only a few consumers subscribe to cellular service (1.6 million nationwide by 1988) and numbering in the U.S. did not allow consumers to identify the cellular network of the called party, and thus making difficult to introduce within network discounts.

The modeling approach needs to make use of specific functional forms to overcome the lack of individual usage information. Individual usage would allow me to model demand in a much more flexible manner but unfortunately such information is not available. All functional forms used in the paper ensure that both the *SCP* and the *IHR* conditions hold in order to obtain a well-behaved, monotonically increasing, concave, nonlinear tariff solution inducing a separating equilibrium so that different consumer types are priced differently for the service.

## 2.1 Model Specification

A monopolist produces a good or service  $x$  at a constant marginal cost  $c \leq \bar{\theta}$  and designs a nonlinear tariff  $T(x)$  to maximize profits:

$$\pi(x) = T(x) - cx. \quad (1)$$

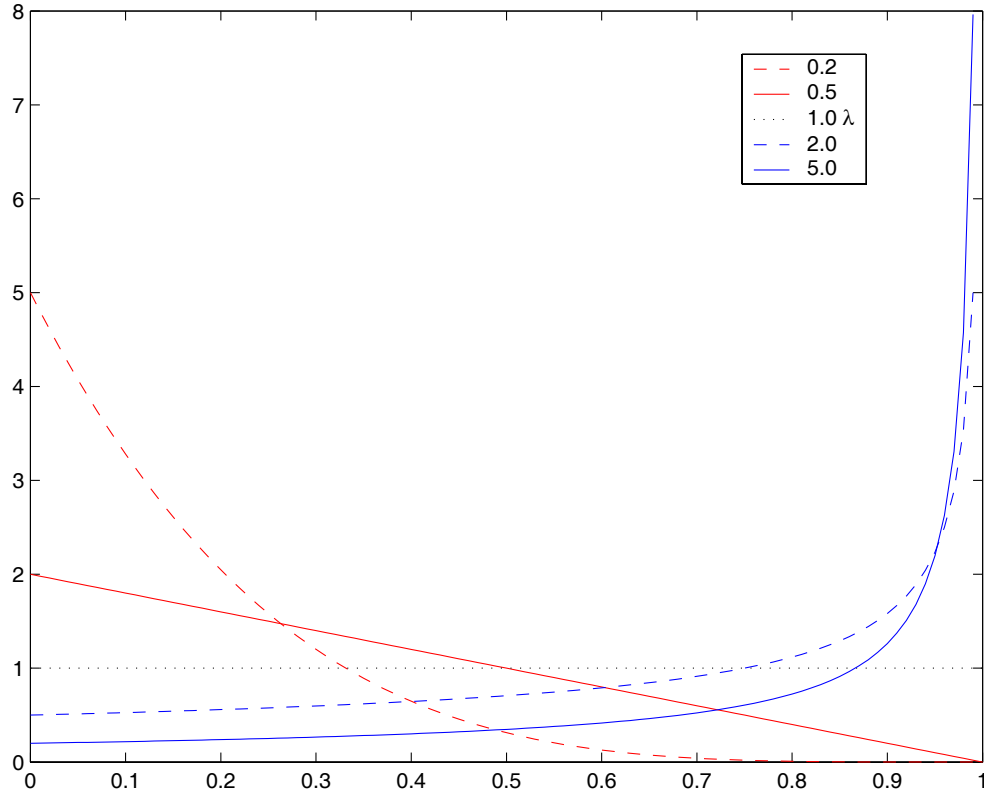
Preferences are indexed by a single-dimensional taste parameter  $\theta$  that captures all heterogeneity of consumers. If a consumer subscribes to the cellular service, she obtains the following net utility from consuming  $x$ :

$$v(x, \theta) = U(x, \theta) - T(x) = \theta x - \frac{\gamma}{2} x^2 - T(x), \quad (2)$$

where  $T(x)$  represents the total monthly payment for  $x$  minutes of cellular telephone usage, and  $\theta$  is assumed to be distributed according to a Burr type XII distribution with parameter  $\lambda$ :

$$\theta \sim F(\theta) = 1 - \left(1 - \frac{\theta - \underline{\theta}}{\bar{\theta} - \underline{\theta}}\right)^{\frac{1}{\lambda}} \quad ; \quad \lambda \geq 0, \quad \theta \in \Theta = [\underline{\theta}, \bar{\theta}]. \quad (3)$$

Figure 1:  $f(\theta)$  — Burr type XII density function



The Burr type XII distribution of  $\theta$  in equation (3) is a restricted beta distribution with parameters 1 and  $\lambda^{-1}$ . The economic interpretation of parameter  $\lambda$  is appealing as it is directly related to the average markups charged by the monopolist to consumers with diverse valuations.<sup>4</sup> Different values of  $\lambda$  identify whether high-valuation consumers are more or less numerous than low-valuation consumers. This is clearly shown in Figure 1. If  $\lambda = 1$  then  $\theta$  is uniformly distributed. If  $\lambda > 1$ , there are more numerous high-valuation than low-valuation customers and *vice versa* when  $\lambda < 1$ . If  $\lambda = 0$ , distribution (3) becomes degenerate at  $\theta = \underline{\theta}$ , asymmetric information turns out to be irrelevant and homogeneous consumers will be efficiently priced by means of a single two-part tariff.

Finally from maximizing (2), the demand of any consumer type  $\theta$  is linear in the marginal tariff:

$$x(p, \theta) = \frac{\theta - p}{\gamma}. \quad (4)$$

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<sup>4</sup> The Burr type XII distribution of  $\theta$  in equation (3) fulfills the *IHR* property as long as  $\lambda \geq 0$ . See Johnson, Kotz, and Balakrishnan (1994, §12.4.5) for further details. Miravete (2002, Appendix) and Miravete (2005) analyze in detail the relationship between  $\lambda$  and the markup charged to different single-dimensional consumers.

## 2.2 Multipart Tariff

A fully nonlinear tariff would attempt to maximize expected profits by extracting as much informational rents as possible from each consumer type while still inducing them to self-select their consumption level according to their type. However, cellular carriers, as well as many firms in numerous other industries, do not offer the fully nonlinear tariff to their consumers due either to institutional issues or, as I argue, to the existence of non-negligible commercialization costs associated with the offering of each new tariff option. The monopolist therefore solves a slightly different problem in which he finds a set of monthly fees and usage rates that characterize a menu of  $n - 1$  tariff options. This section formalizes this problem.

An  $n$ -part tariff consists of a fixed fee schedule  $A_0$  plus a block-declining price schedule with  $n - 1$  segments such as  $A_k < A_{k+1}$  and  $p_k > p_{k+1}$ , *i.e.*, the more expensive the fixed fee is, the lower the corresponding rate per minute becomes. Thus, payments according to tariff option  $k$  are given by  $T_k(\theta) = A_k + p_k x(p_k, \theta)$ . Since consumers' demand functions are uniquely ordered by their types, consumers of type  $\theta$  choose the tariff option  $k$  if  $\theta_k < \theta < \theta_{k+1}$  where  $\theta_k$  (respectively  $\theta_{k+1}$ ) is the type indifferent between tariff plan  $k$  and  $k - 1$  (respectively  $k + 1$  and  $k$ ).

To obtain the optimal multipart tariff solution for a monopolist who wants to offer an  $n$ -part tariff given by  $\{A_k, p_k\}, k = 1, \dots, n - 1$ , we need to find the optimal sequence of marginal tariffs  $p_1 > \dots > p_{n-1}$  and switch types  $\theta_1 < \dots < \theta_{n-1}$  that maximizes his expected profits given the demand, the distribution of types, and the restricted tariff strategy represented by the number of  $n$ -part tariffs offered. The profit contribution of consumers of type  $\theta$  from purchasing tariff option  $k$  is:

$$\Pi_k = A_k[F(\theta_{k+1}) - F(\theta_k)] + (p_k - c) \int_{\theta_k}^{\theta_{k+1}} x(p_k, \theta) dF(\theta), \quad (5)$$

so that after aggregating across consumer types we obtain that the overall expected profits when a monopolist offers an  $n$ -part tariff is:

$$\Pi(n) = \sum_{k=1}^{n-1} \int_{\theta_k}^{\theta_{k+1}} [A_k + (p_k - c)x(p_k, \theta)] dF(\theta). \quad (6)$$

Similarly, the consumer payoff of subscribing to tariff option  $k$  is:

$$CS_k = \int_{p_k}^{\infty} x(p, \theta) dp - A_k, \quad (7)$$

and thus, the total expected consumer surplus with  $n - 1$  options becomes:

$$CS(n) = \sum_{k=1}^{n-1} \int_{\theta_k}^{\theta_{k+1}} \left[ \int_{p_k}^{\infty} x(p, \theta) dp - A_k \right] dF(\theta). \quad (8)$$

Without income effects, equation (7) determines the incremental fixed fee that extracts the maximum informational rents from the switching type who is indifferent between subscribing to tariff plan  $k$  and  $k - 1$ :

$$A_k - A_{k-1} = \int_{p_k}^{p_{k-1}} x(p, \theta_k) dp, \quad (9)$$

and thus, the fixed fee of tariff option  $k$  is found recursively as:

$$A_k = A_0 + \sum_{j \leq k} \int_{p_j}^{p_{j-1}} x(p, \theta_j) dp. \quad (10)$$

Therefore, combining (6) and (9), the objective function of a monopolist using an  $n$ -part tariff becomes:

$$\Pi(n) = \sum_{k=1}^{n-1} \left\{ \int_{\theta_k}^{\theta_{k+1}} (p_k - c) x(p_k, \theta) dF(\theta) + (1 - F(\theta_k)) \int_{p_k}^{p_{k+1}} x(p, \theta_k) dp \right\}. \quad (11)$$

To obtain the optimal marginal rate  $p_k$ , the two-part tariff option  $k$  needs to fulfill the same optimality condition of a fully nonlinear tariff although averaged over those consumers that choose tariff option  $k$ :

$$p_k : \int_{\theta_k}^{\theta_{k+1}} \left[ (p - c) \frac{\partial x(p, \theta)}{\partial p} + \frac{1 - F(\theta)}{f(\theta)} \frac{\partial x(p, \theta)}{\partial \theta} \right] dF(\theta) = 0, \quad \text{at } p = p_k. \quad (12)$$

Since each optional two-part tariff is not designed in isolation from the rest of the options of the menu, the monopolist also has to determine the optimal switch type  $\theta_k$  associated with each option:

$$\theta_k : \int_{p_k}^{p_{k-1}} \left[ (p - c) \frac{\partial x(p, \theta)}{\partial p} + \frac{1 - F(\theta)}{f(\theta)} \frac{\partial x(p, \theta)}{\partial \theta} \right] dp = 0, \quad \text{at } \theta = \theta_k, \quad (13)$$

which is the average of the optimality condition of a fully nonlinear tariff averaged over the interval of marginal rates of adjacent tariff options. Making use of the functional forms of Section 2.1, the first optimality condition (12) becomes:

$$\int_{\theta_k}^{\theta_{k+1}} \left[ (p_k - c) \left( \frac{-1}{\gamma} \right) + \lambda(\bar{\theta} - \theta) \left( \frac{-1}{\gamma} \right) \right] \frac{1}{\lambda(\bar{\theta} - \underline{\theta})} \left( \frac{\bar{\theta} - \theta}{\bar{\theta} - \underline{\theta}} \right)^{\frac{1}{\lambda} - 1} d\theta = 0, \quad (14)$$

which after some algebra becomes the following equivalent condition:<sup>5</sup>

$$\lambda \left[ (\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}+1} (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}+1} \right] - (1 + \lambda)(p_k - c)\lambda \left[ (\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}} (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}} \right] = 0, \quad (15)$$

from which it is easy to obtain an expression of the marginal rate  $p_k$  as a function of marginal cost  $c$ , the degree of asymmetry of information  $\lambda$ , and the switch types that delimits the share of consumers choosing tariff plan  $k$ :

$$p_k = c + \frac{\lambda}{1 + \lambda} \frac{(\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}+1} - (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}+1}}{(\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}} - (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}}}. \quad (16)$$

Similarly, the second optimality condition can be written as:

$$\int_{p_k}^{p_{k+1}} \left[ (p - c) \left( \frac{-1}{\gamma} \right) + \lambda(\bar{\theta} - \theta_k) \left( \frac{-1}{\gamma} \right) \right] dp = 0, \quad (17)$$

leading to:

$$p_k + p_{k+1} = 2 [c + \lambda(\bar{\theta} - \theta_k)], \quad (18)$$

which combined with equation (16) for  $p_k$  and  $p_{k+1}$  leads to the following second order nonlinear difference equation in switch types that determines the optimal sequence  $\theta_1 < \dots < \theta_{n-1}$  as a function of  $(\lambda, \bar{\theta})$  only:

$$2(1 + \lambda)(\bar{\theta} - \theta_k) = \frac{(\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}+1} - (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}+1}}{(\bar{\theta} - \theta_{k+1})^{\frac{1}{\lambda}} - (\bar{\theta} - \theta_k)^{\frac{1}{\lambda}}} + \frac{(\bar{\theta} - \theta_k)^{\frac{1}{\lambda}+1} - (\bar{\theta} - \theta_{k-1})^{\frac{1}{\lambda}+1}}{(\bar{\theta} - \theta_k)^{\frac{1}{\lambda}} - (\bar{\theta} - \theta_{k-1})^{\frac{1}{\lambda}}}. \quad (19)$$

Once the optimal sequence of switch points  $\theta_1 < \dots < \theta_{n-1}$  is found, equation (16) produces the optimal sequence of marginal rates  $p_1 > \dots > p_{n-1}$  for any given value of  $(\lambda, \bar{\theta}, c)$ . Adding the value of  $\gamma$ , equation (10) produces the optimal fixed fee  $A_k$  associated with the  $k^{th}$  tariff option:

$$A_k = A_0 + \sum_{j \leq k} \frac{p_{j-1} - p_j}{2\gamma} \cdot [2\theta_j - (p_{j-1} + p_j)], \quad (20)$$

which after making use of (16) and (18) becomes:

$$A_k = A_0 + \sum_{j \leq k} \frac{\lambda [2\theta_j - (p_{j-1} - p_j)]}{\gamma(1 + \lambda)} \cdot \left[ \frac{(\bar{\theta} - \theta_j)^{\frac{1}{\lambda}+1} - (\bar{\theta} - \theta_{j-1})^{\frac{1}{\lambda}+1}}{(\bar{\theta} - \theta_j)^{\frac{1}{\lambda}} - (\bar{\theta} - \theta_{j-1})^{\frac{1}{\lambda}}} - \frac{(\bar{\theta} - \theta_{j+1})^{\frac{1}{\lambda}+1} - (\bar{\theta} - \theta_j)^{\frac{1}{\lambda}+1}}{(\bar{\theta} - \theta_{j+1})^{\frac{1}{\lambda}} - (\bar{\theta} - \theta_j)^{\frac{1}{\lambda}}} \right]. \quad (21)$$

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<sup>5</sup> Notice that in the limit, as the number of parts goes to infinity, the increments  $\theta_{k+1} - \theta_k$  and  $p_k - p_{k-1}$  become negligible and any of the two previous first order conditions become identical to the well-known optimality condition of a fully nonlinear tariff.

Finally, the multipart tariff problem is also characterized by a couple of boundary conditions given by the behavior of the highest valuation consumer and the marginal cutoff customer. Since all consumers above the lowest active type participate in the market, it must be the case that the highest active type when an  $n$ -part tariff is offered is also an active consumer:

$$\theta_n = \bar{\theta}. \quad (22)$$

Similarly, the first active consumer needs to be indifferent about purchasing at all:

$$x(p_0, \theta_1) = 0. \quad (23)$$

This condition requires that  $p_0 = \theta_1$  which is the customer's valuation of the first unit. If a consumer does not subscribe to cellular service she cannot obtain any rents. Hence, I require that  $A_0 = \underline{U} = 0$ .

### 2.3 Optimal Number of Optional Tariffs

The previous section solves the optimal  $n$ -part tariff given any set of structural parameters  $\omega = (\lambda, \theta_1, \bar{\theta}, \gamma, c)$  that characterizes the demand, distribution of consumer types, and marginal cost of a monopolist in a particular market and time. However, the model is not completely specified because the number of tariff options that the monopolist offers to his customers remains undetermined.

In order to close the model I will assume that the introduction of a new tariff option is associated with a fixed cost of commercialization  $\zeta$ . This cost may comprise the costs of designing the optimal tariff by an operations research department, the costs of an information technology department to implement the new tariff in the company's billing system, or the costs of training the salesforce to market the new product to potential customers. Thus, instead of (11), the monopolist maximizes a slightly different profit function in order to account for these commercialization costs and chooses optimally the number of parts of the multipart tariff:

$$n \in \operatorname{argmax}_{v \in \mathbb{N}} \Pi(v | \omega) - v \cdot \zeta, \quad (24)$$

where  $\Pi(v | \omega)$  is the expected profits of a monopolist that offers the optimal  $v$ -part tariff in a market characterized by  $\omega = (\lambda, \theta_1, \bar{\theta}, \gamma, c)$  as given by equation (11). If a firm offers an  $n$ -part tariff in a market characterized by  $\omega$ , the incremental profits from offering  $n - 1$  instead of  $n - 2$  options should exceed the marketing and commercialization costs  $\zeta$  of that same firm. At the same time the incremental profit of offering  $n$  rather than  $n - 1$  options should not justify introducing the  $n^{th}$  tariff plan. Thus, the number of tariff options offered must fulfill the following inequalities:

$$n - 1 : \Pi(n | \omega) - \Pi(n - 1 | \omega) > \zeta > \Pi(n + 1 | \omega) - \Pi(n | \omega), \quad (25)$$

where  $\Pi(1 | \omega)$  denotes the maximum of the expected profits between uniform pricing and a flat fee.<sup>6</sup> These inequalities are the basis of the interval estimates of the commercialization costs offered in this paper. The model of Section 2.2 offers a formulation useful to compute the structural parameters  $\omega = (\lambda, \theta_1, \bar{\theta}, \gamma, c)$  from equilibrium conditions defining a particular menu of optional tariffs. However, there is nothing in the data that allows me to identify the unobservable commercialization costs  $\zeta$ . Therefore, the estimation approach of Section 4 will take the number of tariff options offered in a particular market and time as given and then, once  $\omega$  has been computed, equation (11) can be used to estimate the profits that such a set of parameters would generate with a different number of tariff options. This equilibrium approach can be used to evaluate both the foregone profits of not offering an additional tariff option, of not offering a fully nonlinear tariff, or computing interval estimates of  $\zeta$  by means of the equilibrium incremental profits condition resulting from (25) after adding or subtracting one option to the multipart tariff actually offered to consumers in a particular market and time.

### 3 The Early U.S. Cellular Telephone Industry

By the mid 1980s, after debating for over a decade about standards, regulations, and licensing procedures, the Federal Communications Commission (FCC) granted permission for the creation of 305 non-overlapping, duopolistic, cellular markets around U.S. standard metropolitan statistical areas (SMSAs). In 1981, the FCC set aside 50 MHz of spectrum in the 800 MHz band for cellular services. One of the two cellular channel blocks in each market —the B block or *wireline* license— was awarded to a local *wireline* carrier, while the A block —the *nonwireline* license— was initially awarded by comparative hearing to a carrier other than the local *wireline* incumbent.

For the first time, cellular technology used low-powered transmitters that exhausted the allocated bandwidth within small cells. A single conversation with the older high-powered transmitters of car phones used a channel within a radius of about 75 miles. The FCC required that the low-powered transmitters of the new cellular technology use these channels within a maximum radius of 30 miles. Hausman (2002, §2.1) documents how the combination of cell splitting and sectorization increased capacity by a factor of 8 relative to pre-existing, non-cellular, car telephone technology. Only a few affluent customers subscribed to the monopoly supplied car phone service, and thus, the expected return of the new tech-

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<sup>6</sup> Wilson (1993, §8.3) shows that if IC is fulfilled and the distribution  $F(\theta)$  is IHR, then the incremental profits of adding an additional tariff option are positive but rapidly decreasing in the number of tariff options offered. Thus, commercialization costs will eventually exceed the incremental profits of offering an additional tariff option, therefore effectively limiting the optimal number of tariff options offered.

nology was very high as the cellular technology promised to ease access to a much larger market. The substantial increase in communication capabilities and the moderate costs of investment prompted up to 579 contenders to apply for a single *nonwireline* license.

Licenses were awarded in ten tiers, from more to less populated markets, beginning in 1983. In general the *wireline* licensee offered the service first and enjoyed a temporary monopoly position until the *nonwireline* carrier entered the market, normally within six months of being awarded the license as required by the FCC. However, the administrative review process to award licenses among hundreds of contenders only based on technical issues and investment commitments of applicants proved to be far more costly than expected.<sup>7</sup> After awarding the first thirty SMSA licenses by means of this expensive and time consuming *beauty contest*, and while the application review of the second tier of thirty markets was on its way, rules were adopted to award the remaining *nonwireline* licenses through lotteries. Court appeals against the administrative award of the *nonwireline* licenses in the earlier tiers, and legal, technical, or managerial difficulties to start operating the lottery-awarded licenses in subsequent tiers led to a situation of temporary monopoly in many local cellular markets.

These are exactly the data used in the present study. I use detailed tariff information about the largest fifty *wireline* license holders who enjoyed a monopoly position in one of these SMSAs between 1984 and 1988. I focus on the monopoly period to avoid any strategic arguments that may arise when firms design their tariffs in competition with each other.<sup>8</sup> Data include the number of tariff plans, their monthly subscription fee, and rate per minute during peak hours (a common 11 to 13 hour band at that time). In addition, tariff data are complemented with market-specific demand and cost information, ownership dummies, and an indicator related to the market coverage in each SMSA. Since there is little variation in the number of tariffs offered across markets during these four years I only include the information from the first and last quarters in which the market was served by a single firm. This procedure avoids oversampling of the earlier markets for which many more quarterly (identical) observations are available.

Table 1 defines all variables used in this paper and presents their sample distribution. I will briefly justify here the inclusion of these variables for the empirical analysis of Section 4, aimed to document correlations between these observable regressors and foregone profits. Demand might be higher or lower and —perhaps even more importantly— more or less dispersed depending on the size of the market (POPULATION, BUSINESS, GROWTH), the income per capita of its customers (INCOME), and some other

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<sup>7</sup> The FCC itself did not obtain any revenue from awarding the licenses. Hazlett and Michaels (1993) study the economic consequences of this inefficient license awarding mechanism. See a further description of this market in Busse (2000, §2.1) as well as the account of the entry policy and regulation of these markets by Shew (1994). Murray (2002) offers a detailed review of the early development of this industry.

<sup>8</sup> Miravete (2007a) addresses whether the number of tariff plans that implement the optimal nonlinear tariff has any strategic value in a duopolistic market.

**Table 1: Descriptive Statistics and Definitions**

Variable	Definition	Mean	Std.Dev.
BUSINESS	Thousands of high potential business establishments	44.9400	68.7888
COMMUTING	Commuting time in minutes	26.1000	2.7949
GROWTH	Percent growth of population in the 1980's	1.2398	1.1185
INCOME	Income in 1986 thousand dollars	27.7453	3.4595
POPULATION	Market population in millions	1.6703	1.8399
WAGE	Index of annual wages for cellular industry	7.1426	1.6591
PRIME	One-period lagged prime lending rate	10.0414	1.1404
REGULATED	Dummy: New tariffs need to be approved by regulator	0.4516	0.5004
BELL	Dummy: License owned by a firm of the former Bell System	0.8387	0.3698
COVERAGE	$1.3 \times \text{TCELLS} / (\text{BUSINESS} + 250 \times \text{POPULATION})$	0.0652	0.0670
<i>Profits (*)</i>	Expected profits per potential customer in dollars	13.6187	7.7812
<i>Percent Profits (*)</i>	Share of potential profits secured by simple pricing	0.9865	0.6019
<i>Marketing Costs (*)</i>	Average of foregone profits per customer in dollars	0.3520	0.3976
PLANS	Number of non-dominated peak tariff options offered	1.6559	0.8007

Sources: Cellular Price and Marketing Letter, Information Enterprises, various issues, 1984-1988; Cellular Business, various issues, 1984-1988; 1989 Statistical Abstracts of the United States, U.S. Department of Commerce, Bureau of the Census, using the FCC Cellular Boundary Notices, 1982-1987, available in *The Cellular Market Data Book*, EMCI, Inc.; and BOMA Experience Exchange Report: Income/Expense Analysis for Office Building, various issues, 1985-1989. Variables marked (\*) are the result of simulations once the structural parameters of the model have been estimated. Sample size includes 93 observations.

market characteristics such as average commuting time (COMMUTING) that might be potentially related to the usage of cellular telephones.

In order to control for variations of costs across markets I include a WAGE index as well as PRIME, the lending rate of each market, to capture the cost of financing cellular equipment and investments.

An important variable for determining the cutoff type  $\theta_1$  is the percentage of subscribers among potential customers (COVERAGE). In the absence of individual data, this variable is of key importance in identifying the marginal consumer type which is indifferent between participating in the market or not. In order to define this variable we assume that the potential market in each SMSA is determined by the number of (four member) households plus the number of businesses that belong to industries considered likely to be cellular subscribers of the cellular technology, *i.e.*,  $\text{COVERAGE} = 1.3 \times \text{TCELLS} / (\text{BUSINESS} + 250 \times \text{POPULATION})$ , where TCELLS denotes the number of antennae deployed in each market.<sup>9</sup>

I also include the dummy indicator REGULATED among the regressors as the magnitude of foregone rents could be determined by the pricing behavior of firms facing different regulatory environments. Pricing regulation was not homogeneous across SMSAs as it was a competence of state regulatory commissions. About half of the sample falls within the category of markets where state regulators had to review and approve any tariff increase of the *wireline* carrier. Shew (1994, §3) argues that cellular carriers, confronting

<sup>9</sup> Parker and Röller (1997, §4) report that one antenna could serve between 1,100 and 1,300 subscribers for the average use of cellular telephony at that time. Doctors, lawyers and contractors were thought to be among the professions most likely to be users of cellular telephones.

**Table 2: Tariff Features**

Option No.	Monthly Fee		Rate per Minute	
	Mean	Std.Dev.	Mean	Std.Dev.
<i>Markets with ONE option</i> (56 observations)				
1	28.78	(11.50)	0.39	(0.07)
<i>Markets with TWO options</i> (23 observations)				
1	14.13	(4.96)	0.55	(0.13)
2	40.68	(9.40)	0.38	(0.10)
<i>Markets with THREE options</i> (16 observations)				
1	3.24	(1.29)	0.63	(0.14)
2	15.65	(8.62)	0.46	(0.07)
3	33.41	(18.29)	0.31	(0.10)

Mean and standard deviations (between parentheses) of monthly fixed fees  $A_i$  and rate per minute  $p_i$  are measured in dollars.

the uncertainty of the behavior of this market and fearing future regulatory opposition to tariff increases, had many tariff options approved at the startup of their license, when it was easier. Controlling for this variable will allow me to identify whether the existence of later regulatory review had any effect on the magnitude of foregone rents or pricing strategies.

Finally, data also include an indicator of whether the largest shareholder of each carrier used to be part of the BELL system, as well as the number of (effective) tariff plans offered by these firms in different markets. The firm indicator aims to capture whether pricing strategies respond mostly to past experience or cost advantages by well-established firms rather than newcomers. Table 2 shows that firms offered very few non-dominated tariff options, *i.e.*, those that are the least expensive plan for a non-negligible segment of usage during the peak period. The increase in options translated into new ones with lower monthly fees to ease subscription. As expected, these new tariff options also priced telephone usage at a higher rate per minute in order to provide the right incentives (discounts) to induce separation of intensive from sparse consumers.

## 4 Empirical Analysis

In this section I compute the estimates of expected, foregone, and incremental profits for each market-time observation of the sample. The mechanics of the estimation can be summarized as follows:

1. Using the tariff information available for each market-time combination, I use the model of Section 2.2 to obtain an estimate  $\omega = (\lambda, \theta_1, \bar{\theta}, \gamma, c)$  independently for each market and time.

2. Each independent estimate  $\hat{\omega}$  attempts to match the particular  $n$ -part tariffs offered by a monopolist in a particular market and time. Any discrepancy between the actual fixed fees and usage rates and those predicted by the model of Section 2.2 are due to approximation errors driven by the functional forms assumed to solve the nonlinear pricing problem. I then use equation (11) to compute  $\Pi(v | \hat{\omega})$ , for  $v \in \{1, 2, n-1, n, n+1, \infty\}$ .
3. These expected profit estimates under alternative numbers of options allow me to compute the foregone profits of not adding an additional tariff, the share of maximum attainable profits that the actual pricing strategy or a simple two-part tariff is able to secure, by how much profits increase relative to uniform pricing, as well as the interval estimate of commercialization costs  $\zeta$ .
4. Since these estimations are repeated for each market and time, the obtained distribution of foregone profits are regressed against observable, exogenous, market-based socioeconomic and demographic variables to illustrate which market characteristics are more relevant in determining the magnitude of these foregone profits.

Section 4.1 discusses how to estimate  $\omega$  from the available information while Section 4.2 describes how expected profits, marketing costs, and the decision to offer more or fewer tariff options varies across markets. Section 4.3 documents the low return to increasing the complexity of tariffs.

#### 4.1 Structural Parameters

The structural parameters  $\omega$  fully capture the effect of all market characteristics, observed and unobserved, for each market and time. Computing  $\omega$  market by market is not only convenient for computational reasons, but also reasonable from an economic standpoint unless consumer decisions were correlated across different cities. Arbitrage across markets was not feasible because of the elevated roaming charges to make or receive calls from other cities and thus, consumers could only subscribe the cellular service offered by the local monopolist. Thus, the pricing decisions of each monopolist with respect to consumers will be independent across markets and carriers.<sup>10</sup>

In order to compute the structural parameters of the model we have to find the set  $\omega = (\lambda, \theta_1, \bar{t}, \gamma, c)$  that generates the closest multipart tariffs to those available for each market-time combination of our data while taking the number of parts  $n-1$  as given. Thus, for each candidate estimate of  $\omega$  we have to compute the prediction of the monthly fee and marginal rate offered in each market as those that maximize profits within the family of  $n$ -part tariff options. Let  $\{\hat{A}_k(\omega), \hat{p}_k(\omega)\} \in \mathbb{R}_+^{2k}$  solve the problem of Section 2.2 as

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<sup>10</sup> Recovering  $\omega$  in the first stage and then exploiting the cross-market variation of demographics to explain the behavior of  $\omega$  is a two-stage procedure known to be valid since the work of Chamberlain (1982). Crawford and Shum (2007) make use of this same approach in a discrete type screening model.

summarized by equations (16) and (21) for a candidate value of the parameters of the model  $\omega$  in a market in which  $k = n - 1$  tariff options are offered to consumers. The estimate  $\hat{\omega}$  should minimize the distance between the features of the actual tariff options and those predicted by our model:

$$L_1(\omega) = \sum_{k=1}^{n-1} [\hat{A}_k(\omega) - A_k]^2, \quad (26a)$$

$$L_2(\omega) = \sum_{k=1}^{n-1} [\hat{p}_k(\omega) - p_k]^2. \quad (26b)$$

The value of the cutoff type  $\theta_1$  predicts the share of consumers that participate in the market. Thus, I also require that the model not only predicts the tariff properly, but also the market penetration:

$$L_3(\omega) = [1 - F(\theta_1) - \text{COVERAGE}]^2 = \left[ \left( \frac{\bar{\theta} - \theta_1}{\bar{\theta} - \underline{\theta}} \right)^{\frac{1}{\lambda}} - \text{COVERAGE} \right]^2, \quad (27)$$

where  $\underline{\theta} = 0$  by assumption and  $\text{COVERAGE}$  is the available measure of market penetration for each SMSA.

The next two conditions close the model by setting the maximum consumption  $\bar{x}$ , and the average monthly bill. Attending to the consumption pattern of this early market I set the maximum usage for each predicted  $n$ -part tariff to  $\bar{x} = 500$ . Thus:

$$L_4(\omega) = \left[ \frac{\bar{\theta} - p_k}{\gamma} - 500 \right]^2. \quad (28)$$

Finally, I require that the average bill equals \$100 a month.<sup>11</sup> This number partially overcomes my lack of information about the distribution of individual consumption, thus generating meaningful economic predictions. We therefore require that:

$$L_5(\omega) = \left[ \sum_{k=1}^{n-1} \left\{ \int_{\theta_k}^{\theta_{k+1}} p_k \frac{\bar{\theta} - p_k}{\gamma} \frac{1}{\lambda(\bar{\theta} - \underline{\theta})} \left( \frac{\bar{\theta} - \theta_k}{\bar{\theta} - \underline{\theta}} \right)^{\frac{1}{\lambda}-1} d\theta + \left( \frac{\bar{\theta} - \theta_k}{\bar{\theta} - \underline{\theta}} \right)^{\frac{1}{\lambda}} \int_{p_k}^{p_{k+1}} \frac{\bar{\theta} - p_k}{\gamma} dp \right\} - 100 \right]^2. \quad (29)$$

Therefore, the estimate  $\hat{\omega}$  solves:

$$\hat{\omega} \in \underset{\omega \in \mathbb{R}_+^5}{\operatorname{argmin}} \sum_{j=1}^5 \ell_j L_j(\omega), \quad (30)$$

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<sup>11</sup> The 2002 Semiannual Wireless Survey of the Cellular Telecommunications & Internet Association (CTIA) indicates that for 1988, the nationwide average monthly bill for cellular service reached \$98.02. We conducted an extensive search of additional sources of bill information detailed at market level. However, the original data were destroyed because of confidentiality concerns. Our bill data are exactly the same as those used by Hausman (2002), and while incomplete, they are unfortunately the best ones available.

**Table 3: Structural Parameters**

	<i>First Quarter</i>	<i>Last Quarter</i>	<i>Both Quarters</i>
$\lambda$	0.6937	0.8017	0.7050
$\bar{t}$	1.8784	1.7398	1.8430
$\gamma$	0.0082	0.0068	0.0075
$c$	0.2115	0.2014	0.2064
$\zeta_U$	0.5499	0.4705	0.5102
$\zeta_L$	0.1918	0.1901	0.1909
Observations	46	47	93

Median of the empirical distribution of computed structural parameters. Median of  $\zeta_U$  and  $\zeta_L$  are measured in dollars per potential customer of each market.

where weights  $\ell_j$  are only intended to account for the different scales of each component. Simulated annealing —Goffe, Ferrier, and Rogers (1994)— is used to obtain  $\hat{\omega}$ . Each market is estimated ten times to ensure that the unique global minimum is reached (which happens in all cases). Table 3 presents the median of the components of  $\hat{\omega}$  across markets as well as during the first and last quarters in which the monopolist firm operated in each market.

Table 3 points out some interesting features of these markets. First, perhaps with the exception of  $\lambda$ , parameter estimates are quite stable over time. Consumers' willingness to pay for a single minute of telephone usage does not exceed two dollars per minute while marginal cost only amounts to about 10% of such magnitude. Demand is also quite elastic to usage pricing.

The most important result though is that  $\lambda < 1$ , *i.e.*, in this early market, low-valuation consumers are significantly more common than high valuation ones. As a consequence, the average markup of a fully nonlinear tariff would be lower than in the cases studied by Chu and Sappington (2007), Gasmi et al. (1999), Rogerson (2003), or Wilson (1993, §6.4), all of which assume a uniform distribution of types (or alternatively, an equal share of high and low-valuation customers). Therefore, increasing participation will necessarily reduce the equilibrium markup excessively, thus leaving substantial informational rents in the hands of high-valuation consumers in order to sign up consumers from whom only small rents can be extracted. The monopolist will benefit in such circumstances by excluding low-valuation consumers altogether, a common feature of early markets like the U.S. cellular telephone industry during the 1980s in which active consumers needed to purchase very expensive handsets (up to \$3,000) to subscribe. Once I control for the changes in participation induced by tariffs with different numbers of options, the bound estimates of the commercialization or marketing costs fall between 19 and 51 cents per potential customer, *i.e.*, between \$85,500 and \$229,500 for the average market in the sample with a potential customer base of 450,000 users.

**Table 4: Tails of Distribution of Foregone Profits**

<i>TOP MARKETING COSTS</i>			
<i>City</i>	<i>Quarter</i>	<i>Plans</i>	<i>Foregone Profits</i>
Los Angeles, CA	87:2	1	234,333
Miami, FL	84:4	1	226,232
Los Angeles, CA	84:4	1	191,698
Atlanta, GA	84:4	1	66,889
New York, NY	84:4	3	57,849
<i>BOTTOM MARKETING COSTS</i>			
<i>City</i>	<i>Quarter</i>	<i>Plans</i>	<i>Foregone Profits</i>
Pittsburgh, PA	85:4	1	395
Gary, IN	85:4	3	289
Johnson City, TN	86:3	2	140
Gary, IN	86:4	3	125
Detroit, MI	85:3	3	35

Market specific estimates of incremental profits in dollars.

## 4.2 Profitability and Pricing Strategies

The estimation procedure of Section 4.1 allows me to recover the whole distribution of structural parameters  $\hat{\omega}$ , and more meaningfully, the value of expected profits, share of total profits from fully nonlinear pricing secured with simple tariffs and equilibrium value of marketing costs. All these variables are obtained after substituting the estimated  $\hat{\omega}$  into equation (6) for different numbers of tariff options, which requires first solving problem (11) also for different values of  $n$ .

Table 4 presents the markets with larger and smaller estimated marketing costs. The estimated foregone profits are the average from using the upper and lower bounds of the interval estimates  $\zeta_U$  and  $\zeta_L$ . The range of implicit marketing costs varies between \$234,000 per month to just a few dollars. Foregone profits are larger in large cities where firms only offer one tariff option, while they are almost nil in smaller cities where firms offer more numerous tariff options.

Table 5 conducts a similar analysis, this time with respect to the share of potential profits from non-linear pricing secured by few tariff options.<sup>12</sup> Several features shown by these results are worth mentioning. First, the range of foregone profits is quite limited. Even in the market with the largest share of money left on the table, the cellular carrier secures over 95% of potential profits just with one single tariff option. Second, the size of the market does not appear to have any clear influence on this percentage. There are both large and small cities among the top and bottom of the distribution of the percentage of secured total profits. Finally, it is clear that the number of tariff options is strongly correlated with the share of secured

<sup>12</sup> In practice, the fully nonlinear tariff is approximated by a sixteen-part tariff. This number of tariffs is far larger than needed to ensure that foregone profits left are negligible, while increasing the number of tariffs indefinitely is not practical because it increases the computation time exponentially.

**Table 5: Tails of Distribution of Secured Profits**

<i>TOP SHARE</i>			
<i>City</i>	<i>Quarter</i>	<i>Plans</i>	<i>Percentage</i>
Miami, FL	88:2	2	99.98%
Gary, IN	86:4	3	99.83%
Albany, NY	85:4	3	99.78%
Gary, IN	85:4	3	99.71%
Albany, NY	87:1	3	99.67%
<i>BOTTOM SHARE</i>			
<i>City</i>	<i>Quarter</i>	<i>Plans</i>	<i>Percentage</i>
El Paso, TX	86:2	1	95.67%
Sacramento, CA	85:4	1	95.52%
Dallas, TX	86:3	1	95.32%
San Francisco, CA	85:4	1	95.20%
Hartford, CT	88:2	1	95.13%

Market specific estimates of the ratio of expected profits of the current pricing strategy relative to those of the fully nonlinear tariff.

total profits. Firms obtain almost the same profits by offering more complex tariffs than by implementing the fully nonlinear tariff (of course ignoring the marketing cost of offering an infinite number of options).

All this suggests that if I want to describe how observable exogenous demographics are related to expected profits and marketing costs I need to condition on the actual number of tariff options offered by cellular carriers in each market and time because the set of conditions used to recover the parameters is different depending on the number of tariff options offered by the monopolist. But clearly, this is not a one-way relationship, as the number of tariff options in the present equilibrium approach depends on the expected increased profitability and incremental costs of offering additional options. I thus need to estimate a simultaneous equations model that includes the number of tariff options as one of the endogenous variables to be explained. Estimates presented in Table 6 correspond to the following econometric specification:<sup>13</sup>

$$\text{Expected Profits} = \alpha_{10} + \alpha_{11}\text{BUSINESS} + \alpha_{12}\text{COMMUTING} + \alpha_{13}\text{GROWTH} \quad (31a)$$

$$+ \alpha_{14}\text{INCOME} + \alpha_{15}\text{POPULATION} - \alpha_{16}\zeta + \varepsilon_1,$$

$$\text{Marketing Costs} = \alpha_{20} + \alpha_{21}\text{WAGE} + \alpha_{22}\text{PRIME} - \alpha_{23}\zeta + \varepsilon_2, \quad (31b)$$

$$-\zeta = \alpha_{30} + \alpha_{31}\text{REGULATED} + \alpha_{32}\text{BELL} + \alpha_{33}\text{Expected Profits} \quad (31c)$$

$$+ \alpha_{34}\text{Marketing Costs} + \varepsilon_3.$$

<sup>13</sup> Data include demand and cost indicators other than those used in this estimation but besides failing to be significant, these indicators made the estimation quite unstable as the identification restrictions of this system of simultaneous equations were rejected.

**Table 6: Second Stage Estimates**

	<i>Expected Profits</i>		<i>Marketing Costs</i>		PLANS ( $-\zeta$ )	
CONSTANT	1.2403	(2.62)	-3.1877	(3.03)	-2.4964	(1.90)
BUSINESS	0.0018	(2.18)				
COMMUTING	0.0131	(0.70)				
GROWTH	0.1681	(3.72)				
INCOME	0.0181	(1.11)				
POPULATION	-0.0340	(0.77)				
WAGE			-0.0030	(0.08)		
PRIME			0.0080	(0.19)		
REGULATED					0.2434	(1.93)
BELL					0.1274	(1.08)
<i>Profits</i>					0.0235	(0.06)
<i>Marketing</i>					-0.7386	(5.30)
PLANS( $-\zeta$ )	-0.1051	(0.60)	-1.0329	(3.09)		
MW- $R^2$	0.9969					
Observations	93					

Generalized least squares, system, minimum distance estimates with absolute-value t-statistics reported between parentheses. MW- $R^2$  is the system, moment weighted,  $R^2$  as defined in equation (2.3.16) of Judge, Griffiths, Hill, Lütkepohl, and Lee (1985).

In this specification expected profits are a function of demand-related variables while the average marketing costs are made to depend on cost-related variables. In both cases, these regressions are conditioned on  $\zeta$ , the underlying (unobservable) firm specific commercialization cost that determines the actual number of tariff options offered in a particular market. While  $\zeta$  is not observable, the number of tariff options actually offered is proportional to  $-\zeta$ . Thus, in practice, we have to replace  $-\zeta$  by the number of tariff options offered, while the third equation becomes an ordered probit model where the number of tariff options is made a function of expected profits, estimated marketing costs, and other firm and market characteristics potentially relevant in deciding the number of tariff options to offer to consumers in a particular market.

Thus, the system estimation involves two linear equations and an ordered probit. However, the linear equations are conditioned on the value of  $\zeta$  and not on the discrete number of tariff options.<sup>14</sup> Amemiya (1978) shows that this system of equations can easily be estimated. First, all endogenous variables are regressed on all exogenous variables, either by ordinary least squares or as an ordered probit, to produce the reduced form estimates. Then, in a second stage, the structural estimates are obtained by means of a generalized least squares estimator that maps the reduced form parameters into the structural ones by implementing the exclusion restrictions of (31a)-(31c). These are the estimates presented in Table 6.

Results are interesting in characterizing the early U.S. cellular telephone industry. Expected profits are essentially conditioned by the size of the market and its expansion. Significantly, individual consumers

<sup>14</sup> This avoids the well-known problem of incoherency in simultaneous equations with discrete endogenous regressors. See Gourieroux, Laffont, and Monfort (1981), Heckman (1978), Maddala (1983, §7.5), or Schmidt (1981).

are far less important in defining the potential demand than businesses. As for the marketing costs, none of the available cost indicators appear to explain the variation in marketing costs, a magnitude that is admittedly small compared with the large fixed cost of deploying and operating a network of antennae for the first time. These marketing costs are essentially determined by the number of tariff options offered by the firms. As for why firms offer more or fewer tariff options it appears that commercialization costs play a far more substantial part than expected profitability (just from sales, *i.e.*, excluding these same commercialization costs). Moreover, Table 6 provides two additional results of interest. First, it appears that firms are equally likely to offer more or fewer tariff options regardless of whether they used to belong to the BELL system or not. On the contrary, those firms operating in a REGULATED market (about 45% of the present sample), *i.e.*, whenever the introduction of new tariff options needed prior regulatory approval, decided to offer more tariff options.

Shew (1994) argues that early monopolists in this market explicitly attempted to avoid the constraints of future regulatory review by initially introducing several tariff options. This argument has merit because in this early market there were no precedents to judge the performance of pricing behavior of firms that would eventually face competition. Thus, regulators simply approved all tariffs initially submitted with the idea of evaluating their performance in later periods. Table 6 supports the view that the initial proliferation of tariffs was aimed to preempt the effect of potentially restrictive future rate reviews.

### 4.3 The Low Return of Complex Tariffs

The ultimate goal of this paper is to evaluate whether it pays-off to offer very complex tariffs to consumers using a particular “real world” application rather than abstract (although valid) numerical simulations. The case studied in this paper is one of an early industry where, contrary to all previous numerical simulations, the distribution of consumer types is not symmetric and high-valuation consumers are far less frequent than low-valuation ones. In these circumstances, price discrimination works best by excluding low-valuation customers in order to extract a larger share of the informational rents among active high-valuation ones. Serving low-valuation customers rather than excluding them forces the monopolist to give up substantial informational rents from intensive consumers in order to avoid pooling of all types (thus making price discrimination ineffective).

Table 7 documents the limited gains of complex tariffs. Because in this application low-valuation consumers are more numerous than high-valuation ones, the share of total potential profits secured always exceeds 95% (Table 5) with a median exceeding 96.5% in all cases, despite the number of tariff options offered. This percentage increases with the number of tariff options offered and thus leaves very little to be gained. Adding a third tariff option increases the share of secured total profits between 2.14% and 2.42%. In the least favorable scenario (in those markets with just one tariff option), offering three tariff options already

**Table 7: Return to Increasingly Complex Tariffs**

	<i>Flat</i>	<i>Uniform</i>	<i>Two-Part</i>	<i>Three-Part</i>	<i>Four-Part</i>
<i>Markets with ONE Option</i>	78.55	90.97	96.57	98.99	— — —
<i>Markets with TWO Options</i>	69.48	92.98	96.77	99.09	99.62
<i>Markets with THREE Options</i>	57.46	93.95	97.03	99.17	99.65

Median of the percentage of profits from fully nonlinear pricing secured with different pricing strategies.

exceeds Wilson's estimate of the share of total profits secured with five tariff options when the distribution of types is uniform (98.8%). It thus appears that the more asymmetric the distribution of consumer types (the larger the share of low valuation customers), the fewer tariff options needed in order to secure a given level of total profits. Alternatively, given a particular level of marketing costs, the more symmetric the distribution of types is the more tariff options offered by the seller.

Table 7 also reports the very dissimilar performance of two simple pricing strategies: a flat tariff and a single uniform price. First, uniform pricing always secures a far larger share of profits than a single flat tariff. A flat tariff proves to be a less effective pricing mechanism because it cannot discriminate among different usages of active consumers. Profits from a flat tariff are those derived from the participation decision of consumers only. Uniform pricing still excludes many low-valuation consumers and charges a different amount for the different levels of usage. In other words, linear pricing can approximate far better the performance of the optimal two-part tariff than a flat tariff option. Perhaps for this reason prepaid cards (uniform pricing) are popular in the early stages of cellular markets while the use of fixed price contracts with "free minutes" only becomes widespread as the industry matures and competition intensifies.

## 5 Concluding Remarks

The evidence reported in this paper shows that profits from further discrimination decrease very rapidly with the number of options. Indeed, offering three tariff options provides early U.S. cellular telephone carriers around 99% of the potential profits of fully nonlinear pricing. I estimate that the average foregone profits in the sample amounts to 35 cents per month per potential customer (expressed in 1986 dollars).

The paper presents compelling evidence that simple tariffs will provide most of the potential gains to firms and consumers. While Wilson (1993, §8.3) proved that foregone rents decreased rapidly with the number of tariff options offered, this paper has shown that the economic magnitude of these foregone rents after two or three tariff options are offered falls well below the likely *product development costs* associated with the design and commercialization of additional optimal tariff options. Furthermore, this effect is exacerbated in early markets where low-valuation customers are more numerous than high-valuation ones

and a tariff with  $n$  options secures a significantly larger share of potential profits than in environments where consumer types are uniformly distributed.

In light of this evidence, theorists should reconsider the validity of the assumption that offering an infinite number of tariff options is costless. This would be, by far, the most important consequence of this paper. Businesses already make use of simple forms of nonlinear price discrimination rather than complex fully nonlinear tariffs. Following their example will probably allow us to address open questions such as bundling discounts, multidimensional screening and/or competitive nonlinear pricing. In the end, solving for the optimal three-part tariff (two tariff options) amounts to finding two fixed fees and two usage rates, far easier than characterizing a fully nonlinear function. This paper documents that it is likely that if we proceed in such a way, we only ignore less than 1% of the potential profits, perhaps a small price to pay to understand how firms actually price their multiple products.

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