Empirical Modeling of Endogenous Quality Choice: The Case of Cable Television*

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Abstract

The purpose of this paper is to present a framework for the empirical analysis of price and quality choice by a multiproduct monopolist. We do so by demonstrating that well-known techniques from the optimal screening literature used in the theoretical analysis of nonlinear pricing map naturally to the empirical analysis of differentiated product markets. We then apply a generalized one-dimensional screening model recently developed by Rochet and Stole (2001) to analyze price and quality choice for Basic cable television services. Consistent with the theory, our preliminary results suggest significant degradation in product quality relative to first-best levels. Furthermore, our results provide strong support for the nonlinear pricing model with random participation of Rochet and Stole (2001) over the classical model of monopoly quality choice of Mussa and Rosen (1978).

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1 Introduction

Economists have long been interested in measuring the impact to social welfare of the introduction of new goods. This is understandable, as the welfare benefits of new goods are widely viewed as fundamental determinants of increased living standards and economic growth in the long run. Quantifying these benefits, however, can be challenging as it requires flexible estimation of tastes and technology across the spectrum of affected markets. Recent developments in the empirical analysis of differentiated products markets has enabled flexible estimation of empirical models of specific industries using widely available aggregate data. Based on these models, authors in a variety of industries have found the welfare benefits of new goods to be considerable.[1]

Each of these studies has unfortunately taken the set of products offered by firms, both existing and new, as given. This has both positive and normative implications for the estimated welfare measures. Since in equilbrium it is natural to assume that firms base their offerings on consumers' tastes, conditioning on the set of offered products can bias estimated welfare benefits. Even in the absence of this effect, since firms internalize the impact on their existing products of the introduction of new goods, the set of offered products need not correspond to the socially efficient outcome.[2] Measuring any deviations from efficiency is an important first step towards understanding the difference between prive and social incentives to introduce new products, an important issue for investment and competition policy.

The purpose of this paper is to present a framework for the empirical analysis of price and quality choice by a multiproduct monopolist. It extends existing models of differentiated product demand and supply common in the empirical literature by explicitly modeling the choice of product quality by firms. We base this model on the theoretical screening literature used in the analysis of optimal nonlinear pricing.[3] In this framework, consumers have private information about their willingness-to-pay for products or their attributes.[4] A monopolist knows only the distribution of this information and therefore offers a range of products and associated prices designed to induce consumers to self-select into that product that maximizes his expected profit.

The primary contribution of this paper is to demonstrate that the theoretical framework analyzing equilibrium in screening models maps naturally to the empirical analysis of differentiated product demand and supply.[5] This is a surprisingly important insight, as it both (1) provides a set of well-developed analytical techniques useful for finding equilibria with endogenous prices and qualities and (2) delineates the set of problems that may tractably be solved. The latter result is somewhat negative, as solving for endogenous prices and qualities quickly becomes intractable for the class of preferences commonly assumed in empirical

[1] Examples include the seminal work of Trajtenberg (1989) in health care technology, Petrin (1999) in automobiles, Bresnahan (1986), Greenstein (1996), and Bresnahan, Stern, and Trajtenberg (1997) in computers, Hausman (1996) in cereals, and Crawford (2000) in cable television. Bresnahan and Gordon (1996) provides a nice introduction to the issues involved as well as additional papers on the topic.
In addition, the issues raised in this paper apply more broadly to all research involving the structural empirical analysis of differentiated product markets. Further examples include Berry, Levinsohn, and Pakes (1995a), Davis (1997), Rysman (1998), Manuszak (2000), Gaynor and Vogt (2000), and Nevo (2001).

[2] The difference in equilibrium product variety of monopoly, competitive, and socially efficient outcomes has a long history in the theory literature. See (Tirole, 1988, Chapter 2) for a discussion.

[3] Seminal papers in this literature are Mussa and Rosen (1978), Spence (1980), and Maskin and Riley (1984). See Wilson (1993) for a comprehensive analysis and Rochet and Stole (2000) for a recent survey emphasizing multidimensional models.

[4] Throughout this paper, we will use the terms 'products', 'attributes' (or characteristics), and 'qualities' interchangeably.

[5] This point was first demonstrated to our knowledge by Rochet and Stole (2001).

work. Specifically, when consumers have preferences over more than one characteristic of products the firm can control, equilibrium requires the firm solve a multidimensional screening problem, a very difficult undertaking for all but a very small set of special cases.[6] In this paper, we therefore base our empirical model on a generalized one-dimensional screening model recently introduced by Rochet and Stole (2001).

The primary advantage of a model of price and quality choice is that one can accurately measure of the welfare benefits of price *and* quality changes. For example, a standard result in the theoretical literature is that a monopolist will degrade the quality of offerings to all consumers except those with the greatest tastes for quality. Our empirical framework can measure this effect and quantify its importance for consumer and social welfare. Furthermore, by explicitly making quality the choice of firms, it can account for this important response when considering the welfare consequences of other changes in the economic environment, as in the analysis of mergers or changes in the regulatory environment.[7] This permits assessing the robustness of existing research that takes product offerings to be exogenous.

This paper is related to two small empirical literature. The first analyzes the product choices of firms. Mazzeo (1997) and Stavins (1995) consider quality choice in the motel and personal computing industries and find evidence of differentiation to soften price competition and deter entry, respectively. In the closely related entry literature, Bresnahan and Reiss (1987) and Berry (1992) analyze entry decisions in small-town service industries and airlines to estimate the size of entry barriers and quantify the importance of free entry on policies promoting competition. As these examples suggest, the typical focus of papers in this literature is the impact of new product or firm entry on aspects of competitive interaction and not its consequences for consumer or social welfare.[8] This reflects the strong simplifying assumptions on the nature of the economic environment required to conduct an empirical analysis limit one's confidence in drawing inferences about the welfare consequences of product or firm entry. A primary goal of this paper is to provide a framework for extending the scope of analysis in differentiated product industries while allowing sufficient modeling flexibility to incorporate important institutional features of the markets under study.

A second literature has applied principal-agent models of adverse selection similar to the one used in this paper. Bousquet and Ivaldi (1997), Miravete (1997), and Leslie (1997) consider the profit and welfare consequences of nonlinear pricing, while Wolak (1994) assesses the welfare consequences of informational asymmetries in water utility regulation. Our model differs from these in several respects. First, it relies on the generalized one-dimensional screening model of Rochet and Stole (2001). In this model, consumers' participation constraints are assumed to be random (to the firm). As in the canonical adverse selection model, the monopolist develops an optimal tariff that screens consumers according to a one-dimensional preference parameter, but accounts for this random participation in its design. This seemingly innocuous generalization has important implications for the form of the optimal tariff, a fact we demonstrate in our empirical work. Second, reflecting the nature of offered qualities (versus quantities), we generalize the typical nonlinear pricing model model by solving for equilibrium with discrete qualities and continuous types (in

[6] See (Wilson, 1993, Chapter 13), Armstrong (1996), Rochet and Chone (1998), and the survey by Rochet and Stole (2000) for more.

[7] For example, Crawford (2000) finds that cable systems sometimes dramatically changed the quality of their offered services in response to regulations imposed by the 1992 Cable Act and Petrin (1999) finds immediate imitation of the minivan by car manufacturers after its successful introduction by Chrysler. Nevo (2000a) discusses more generally the importance of accurately measuring changes in quality when conducting applied welfare analysis.

[8] A recent exception is Berry and Waldfogel (1996), which analyzes the direction but not the magnitude of consumer welfare benefits of entry in radio broadcasting markets.

process).[9]

We apply our empirical framework to analyze the optimal price and quality choice for Basic cable television services. This is an attractive industry in which to analyze endogenous quality choice for a number of reasons. First, in any given cable market, Basic services differ only in the number and quality of networks offered to consumers. A (generalized) one-dimensional model of consumer preferences is therefore sufficient to describe consumer preferences. Second, there are a large number of cable systems, the vast majority of which are unregulated multi-product monopolists in their local service area.[10] The lack of direct competition lessens the need to consider the competitive consequences of endogenous product quality, expanding the set of models one can bring on bear to the problem. Furthermore, there is considerable variability in service quality across systems.

For this version of the paper, we present results under strong assumptions on the nature of demand and cost. Specifically, we assume that tastes for cable services in each market are given by a discrete distribution with points of support equal to the number of Basic and Expanded Basic services offered by the cable system in that market. This discrete-type/discrete-quality problem simplifies the estimation and provides an example of the type of results possible with further generalization. We further assume tastes are linear and costs quadratic in quality. This corresponds to the canonical model of quality choice by a monopolist first developed by Mussa and Rosen (1978) (hereafter MR) and generalized to allow for random participation by Rochet and Stole (2001) (hereafter RS).

In the empirical analysis, we estimate both the MR and RS models. To do so, we consider each cable market in isolation and infer the unknown parameters of the distribution of consumer tastes by equating the market shares and prices predicted by the model to those observed in the data. Given the estimated parameters, we can then compute the implied quality of each service offered by firms. We also consider estimation using the number of channels provided on each service as an explicit measure of quality (in process). By identifying the structure of preferences and costs, we may not only report the implied quality provided by firms, but also relate it to the characteristics of offered services. We can also simulate the profit and welfare consequences of alternative portfolios of offered qualities.

We obtain three sets of preliminary results. First, from a modeling perspective, our results provide strong support for the nonlinear pricing model with random participation of Rochet and Stole (2001) over the classical principal-agent model under adverse selection of Mussa and Rosen (1978). Specifically, the MR model implies significantly greater quality degradation, so much so it cannot support patterns of prices and qualities observed in the data. Second, consistent with the theory, our results suggest significant degradation in product quality relative to first-best levels. For the model with random participation, offered quality is an estimated 8.3% and 16.4% less in 3-good markets and 31.4% less in 2-good markets. Despite this, consumers would not necessarily be better off with first-best levels of quality. In some markets, firms would not provide the range of products currently offered and consumer and total surplus would fall. Finally, we find mean willingness-to-pay for cable networks suggested by our preliminary estimates differ in favorable ways from previous results using conventional techniques found in Crawford (2000). This suggests controlling for

[9] Models of nonlinear pricing apply equally well to price-quantity (with fixed quality) as price-quality (with fixed quantity) problems. The latter is more common in the differentiated product markets that are the focus of the recent empirical literature.

[10] The industry has gone through a sequence of regulatory phases in the last 20 years (Hazlett and Spitzer (1997)). Most recently, the 1996 Telecommunications Act prohibited price regulation on all but the lowest level of cable television service. Furthermore, content (i.e. quality) regulation is prohibited on First Amendment (freedom of expression) grounds.

endogenous quality may be important for the consistent measurement of consumer tastes in differentiated product markets.

The rest of this paper is organized as follows. In the next section, we survey the recent empirical literature analyzing differentiated product markets. We then survey in Section 3 the theoretical screening literature, demonstrate the natural connection between the two frameworks, and present the RS model that forms the foundation of the empirical analysis. In Section 4, we describe the cable television industry and discuss its suitability for this empirical analysis, followed in Section 5 by the empirical model and results. Section 6 concludes and suggests extensions.

2 Empirical Models of Differentiated Product Markets

In the last decade a significant focus of the empirical literature in industrial organization has been accurately modeling demand and supply in differentiated product markets in applications ranging from antitrust policy and the welfare consequences of new goods to international trade and public finance. The purpose of this section is to briefly survey the recent empirical literature, present the canonical empirical specification, and discuss its applications in a variety of contexts. This discussion serves as a basis for extending this literature to consider models of endogenous quality choice in the balance of the paper.

A majority of empirical research in the 1970's belonged to the Structure-Conduct-Performance (SCP) paradigm. These studies focused on the impact of market structure, taken to be exogenous, on the conduct of firms and its subsequent impact on market performance (e.g. prices, profitability, etc.). A typical specification was that of a cross-section industry-level regression of performance variables on measures of the structure of those markets.[11] This approach came under scrutiny in the 1980's, however, on both economic and econometric grounds. On the one hand, the rise of game theory to completely specify the nature of firm conduct in particular economic environments called into question the maintained hypothesis in the SCP paradigm between structure and conduct; in practice, a range of conduct could obtain from a given market structure (Tirole (1988)). Even absent such concerns, the validity of econometric inferences available from industry cross-sections regressions was simultaneously raised as a subject of concern (Schmalensee (1989)). As a result, the last twenty years has seen IO "return to its roots" with the systematic analysis of particular industries based on economic and econometric models integrated to respect the institutional characteristics of the market under study.[12]

Influential early work in the "new empirical Industrial Organization" included Porter (1983) and Bresnahan (1987).[13] These relied on strong assumptions, however, both about the nature of the economic environment and the sources of statistical error required to conduct an empirical analysis. More recently, models of differentiated products industries have been developed based on the characteristics approach of Lancaster (1971) and discrete-choice econometric models originally developed by McFadden [McFadden (1973), McFadden (1978)]. Recent work by Berry (1994), Berry, Levinsohn, and Pakes (1995a), and Nevo (2001) accounting for price endogeneity and the flexible specification of consumer substitution patterns have increased their appeal by enabling estimation on widely-available aggregate data using less restrictive economic and econometric

[11] Weiss (1989) presents a broad characterization of this line of research.
[12] The work of John Sutton [Sutton (1991),Sutton (1998)] is an important exception.
[13] See Bresnahan and Schmalensee (1987) and the papers contained there for an early overview.

assumptions.

The canonical empirical model in this literature specifies the indirect utility to a consumer i from purchasing a good j in a given market or time period:

$$u_{ij} = X_j'\beta + \xi_j + \mu_{ij} \tag{1}$$

where (X_j, ξ_j) represents observed and unobserved attributes of product j (including price), β represents mean individual tastes for observed characteristics, and μ_{ij} represents unobserved individual tastes for good j. This idiosyncratic structure is often assumed to result from a simple random coefficient structure:

$$\mu_{ij} = X_j'\nu_i + \epsilon_{ij}$$

where ν_i represents a mean-zero, individual-specific deviation from mean tastes for characteristics, β, and ϵ_{ij} represents individual i's idiosyncratic tastes for good j. The joint distribution of μ is derived from the joint distribution of individual taste components, $f_{\nu,\epsilon}(\cdot|\Sigma)$, where Σ parameterizes elements of the higher moments of f.

With the appropriate distributional assumptions on ν and ϵ, this model can generate most of the empirical specifications commonly estimated in the empirical demand literature (Nevo (2000b)).[14] When estimated on aggregate data, product market shares are obtained by assuming that each consumer chooses that good which yields her the highest utility. This implicitly defines the set of individual-specific random variables, (ν, ϵ), such that each good is chosen

$$A_j = \{(\nu, \epsilon) | u_{ij} \geq u_{ik} \ \forall k = 0, 1, \ldots, J\} \tag{2}$$

Market shares are then simply given by the integration of the joint distribution of consumer tastes, $f_{\nu,\epsilon}(\cdot)$, over A_j:

$$s_j = \int_{A_j} f_{\nu,\epsilon}(\cdot) d\nu d\epsilon \tag{3}$$

The supply side is most often specified as a differentiated-product oligopoly with prices as choice variables.[15] Let f index firms and $\mathcal{F}_f$ index each of the $j \in J$ goods produced by firm f. Firms are assumed to maximize their profits, given by

$$\Pi_f = \sum_{j \in \mathcal{F}_f} (p_j - mc_j) M s_j(p) - C_f \tag{4}$$

where mc_j is the marginal cost of producing good j, $s_j(p)$ is its market share as a function of the prices of all goods, p, M is the size of the market, and C_f is the fixed cost of production for firm f. A pure-strategy Bertrand-Nash equilibrium is typically assumed to exist.[16]

Recent applications of this framework include the analysis of antitrust (Nevo (2001)), regulatory policy (Crawford (2000)), spatial competition (Davis (1997)), and the welfare benefits of new goods (Petrin (1999))

[14] An important exception are models with multi-stage budgeting as in Hausman (1996) and Hausman (1997).

[15] Exceptions exist, however. Feenstra and Levinsohn (1995) test the use of prices or quantities as choice variables, while Crawford (2000) and Leslie (1997) consider monopoly pricing.

[16] This unfortunately has support in the theory literature only for particular specifications of the demand structure (Caplin and Nalebuff (1991)).

as well as topics outside the typical domain of IO like trade policy (Goldberg (1995), Berry, Levinsohn, and Pakes (1995b)) and the demand for schooling (Bayer (1998)).

For each of these papers, however, only prices are assumed to be chosen by firms. The characteristics of the offered goods, X, are assumed to be exogenous, and indeed are often used as instruments for prices in the econometric estimation. While a plausible specification in the very short-run, for many problems firms may have considerable control over product characteristics as well as prices when deciding what goods to offer. If so, failing to account for product (or characteristic) endogeneity may bias all the estimated coefficients. The purpose of this paper is to expand firms' decision variables to include such characteristics (which we call quality). To do so, we appeal to the theoretical literature on optimal screening contracts introduced in the next section.

3 Screening Models of Endogenous Price and Quality Choice

The purpose of this section is to briefly survey the theoretical literature analyzing optimal screening models.[17] We begin by presenting a general screening model, compare its structure to the canonical empirical model described in the last section, and discuss solution techniques for single and multi-dimensional models. Given the difficulty with the latter, we conclude this section by presenting the generalized one-dimensional models of nonlinear pricing with random participation of Rochet and Stole (2001) which form the basis of our econometric estimation.

3.1 A Statement of the (Discrete) Problem and Its Solution

Economic Fundamentals Consider a monopolist selling a portfolio of goods, $q \equiv \{q_1, \dots, q_n\}$, whose qualities (or characteristics) can be freely varied over Q, the non-negative orthant of n-dimensional Euclidean space.[18] The monopolist is assumed not to be able to differentiate between individual consumers or groups as in 1st- or 3rd-degree price discrimination. Instead, he is assumed to be able to offer a nonlinear tariff specifying a different total price per quality variant offered, $P(q)$.[19]

Consumers are assumed to be differentiated by a type parameter, $t_i \in \{t_1, \dots, t_m\}$, defined over the n products with respective probabilities, f_i, known to the monopolist. The associated cumulative distribution function is $F_k \equiv \sum_{i=1}^{k} f_i$. Consumer preferences are assumed to be quasilinear in money, $u(q,t) = v(q,t_i) - P(q)$, but no further assumptions are made on v. A consumer of type t_i is assumed to choose that bundle, $q(t_i)$, which maximizes her utility, $U(q,t_i)$, among the offered bundles, $q \in Q$. For ease of notation, let $q_i = q(t_i)$ and $u_i = u(t_i)$. Assume for simplicity that the monopolist offers a separate good to each consumer type. This implies $n = m$ and that goods may be indexed by either i or j. To allow for the possibility of purchase of an outside good, define type t_0 such that $v(q,t_0) = 0$ in which case, $q_0 = 0$, $P_0 = 0$, and $u_0 = 0$. Note that risk aversion and income affects are assumed away in this specification.

In this framework, the monopolist would like to base his tariff on a consumers type, but cannot as this

[17] This is known as the "Nonlinear Pricing Problem" in the mechanism design literature.

[18] The seminal analysis of this problem in one dimension dates to Mirrlees (1971). The exposition in this section borrows heavily from the presentations in Wilson (1996) and Rochet and Stole (2000). See (Fudenberg and Tirole, 1991, Chapter 7) for details and a more general exposition of this framework.

[19] In this literature, a *tariff* typically specifies the total cost to the consumer for a bundle of goods of a given quality, while a *price* typically specifies the cost to the consumer of a given increment of quality.

information is private to the consumer. Instead, the firm knows the distribution of types in the population and selects the tariff that maximizes his expected profit (with the expectation taken over consumers types).[20] In so doing, the monopolist is constrained by two features of consumer behavior. First, consumers of each type will only purchase a good if their utility from so doing exceeds that of the outside option. Second, conditional on buying some good, consumers of each type will only purchase the good assigned to them if their utility from that purchase exceeds the utility from the purchase of any other good. These are called Individual Rationality (or Participation) (IR) and Incentive Compatibility (IC) constraints and are given by:

$$v(q_i, t_i) - P_i \geq v(q_j, t_i) - P_j \quad \forall i, j \tag{5}$$

where $i, j \in \{0, \ldots, M\}$.

Given the framework above, we may specify the firms optimization problem as

$$\max_{P(q)} E[\pi] = \sum_{i=1}^{M} f_i \{P(q_i) - C(q_i)\} \tag{6}$$

subject to the incentive compatibility and individual rationality constraints (5) above, where π measures profits and $C(q_i)$ is a non-decreasing, smooth, and convex cost function. By the Revelation Principle, the monopolist's problem may be solved by maximizing profits over all incentive compatible and individually rational mechanisms, $\{q_i, P_i\}_{t \in T}$ ((Fudenberg and Tirole, 1991, Chapter 7)). Without loss of generality, we can solve for the optimal tariff, $P(q_i)$, by dividing the problem into two component parts: (1) finding an optimal assignment, $q(t_i)$, of qualities to types and (2) finding an optimal transfer of net benefits to types, with associated prices, $P(t_i)$.

Similarity to the Canonical Empirical Model Before describing its solution, it is worth comparing the general screening model to the canonical empirical model described by Equation (1)-(4) and the accompanying discussion.

There are two important similarities and three important differences. First, a critical similarity between the approaches are the presence of the incentive compatibility and individual rationality constraints. Specifically, the utility maximization criterion embodied in Equation (2) in the empirical framework is no different from the IC and IR constraints, (5), in the theoretical approach. In essence, IC and IR in the theoretical model govern the definition of well-specified demand curves for each consumer type. Second, the assumptions on utility are, or can be, almost the same. Let $\beta_i \equiv \beta + \nu_i$ be individual i's tastes for X_j, let $X_j \equiv [q_j \quad P_j]$ define the non-price characteristics and price of good j and $\beta_i \equiv [\tilde{\beta}_i \quad \alpha_i]$ be i's corresponding tastes. Then $u(q_j, t_i) = \frac{1}{\alpha_i} q_j' \tilde{\beta}_i - P_j$ yields a model (almost) identical to the canonical empirical specification.

There remain three important differences between the models. First, firms in the empirical model choose only prices and not qualities. This is a virtue of considering the screening approach, as the purpose of introducing the theory is to extend the empirical specification to include quality choice. Second, types in the theoretical model are discrete (indexed by i) and not continuously distributed as in the empirical model. This

[20] From an empirical perspective, this formulation is equivalent to the monopolist knowing the aggregate demand curve(s) for q, but not the corresponding willingness-to-pay of each consumer.

is more problematic. In many cases, the discrete-good problem can be interpreted, as above, as the outcome facing a discrete distribution of consumer types. That is the approach taken in the empirical model for this version of the paper. It is somewhat unsatisfactory, however, as the number of products offered is often significantly fewer than that suggested by plausible patterns of heterogeneous tastes. We therefore need to extend the discrete-type/discrete-good case to consider continuous types and discrete goods (in process).[21] A final difference is the presence of the idiosyncratic taste component, ϵ_{ij} in the empirical model, but not in the theoretical model. We discuss this difference further when considering the random participation model of Rochet and Stole (2001) in Section 3.4.

3.2 One-Dimension Screening Models

We consider first solving the monopolist's problem in the canonical one-dimensional case first considered by Mussa and Rosen (1978). This provides some intuition about the insights the screening approach can provide. The general multidimensional case is briefly considered in the next subsection.

In the one-dimensional case, $Q \equiv [0, \bar{q}]$, and t_i can be ordered such that, $t_0 < t_1 < ... < t_m$. An important auxiliary condition on consumers utility functions is often imposed in this one-dimensional case. This is the well-known "Single-Crossing Property" requiring that u_{qt} has constant sign (usually, as here, positive). This implies higher types have greater willingness-to-pay for quality at any price, or that consumers may be ordered by their type, t. This has the effect that the monopolist need only be concerned with 'local" incentive compatability constraints, i.e. those between adjacent types.

In this case, the monopolists profit may be written as

$$\begin{aligned} \max_{q_i, P_i} E[\pi] &= \sum_{i=1}^{n} f_i\{P(q_i) - C(q_i)\} \\ &= \sum_{i=1}^{n} f_i\{S(q_i, t_i) - u_i\} \end{aligned} \tag{7}$$

where, as is conventional in the screening literature, we've rewritten the profit from each type as the total surplus to that type less his utility, $P(q_i) - C(q_i) = S(q_i, t_i) - u_i$, where $S(q_i, t_i)$ is the total surplus function. This simplifies the introduction of the incentive compatibility constraints into the objective function. In this reformulated problem, the monopolist solves for the optimal *utility*-quality schedule and determines optimal prices (given utilities) from the binding incentive compatibility constraints.

To solve, use the incentive compatability constraints to replace u_i in the objective function via integration by parts:

$$\max_{q_i, u_1} E[\pi] = \sum_{i=1}^{M} f_i\{S(q_i, t_i) - \frac{1 - F_i}{f_i}[v_q(q_i, t_{i+1}) - v_q(q_i, t_i)] - u_1\} \tag{8}$$

where $v_q \equiv \frac{\partial v}{\partial q}$, u_1 is the utility of the lowest type, t_1, and $\frac{1-F_i}{f_i}$ is the inverse of the hazard rate.[22] This

[21] Measuring the loss in profits to firms from offering discrete instead of continuous line of products is an interesting empirical measurement question.

[22] The hazard rates gets its name from a temporal context. If we suppose $F(t)$ measures the probability of failure of a machine by time t, $1 - F(t)$ measures the probability it lasts until at least time t. The hazard rate then measures the conditional probability that it fails at time t given that it has lasted until that time.

is the well-known "virtual surplus" function (Myerson (1991)) yielding the total surplus generated by the monopolist's product offerings less the information rents which must be left to consumers of each type.

This problem may easily be solved by setting the utility of the lowest type to zero, $u_1 = 0$, and maximizing the resulting unconstrained objective function w.r.t. q_i. This solution satisfies

$$S_q(q_i, t_i) = \frac{1 - F_i}{f_i}[v_q(q_i, t_{i+1}) - v_q(q_i, t_i)] \tag{9}$$

for $i = 1, \ldots, m-1$, with q_m given by the solution to $S_q(q_m, t_m) = 0$. The latter result implies there is "no distrotion at the top," a common result in incentive theory.

To find the optimal nonlinear tariff, $P_i \equiv P(q_i)$, one first solves (9) for q_i, obtains u_i from the incentive compatibility constraints, and finally calculates $P_i = v(q_i, t_i) - u_i$.[23] Figure 1 demonstrates graphically the solution for the one-dimensional case with $n = 3$.

3.3 Multidimensional Screening Models

Things quickly get more difficult in multidimensional screening models. This is so for several reasons. First, there is no inherent ordering of types as in the single-dimensional case. This implies that the set of incentive compatibility constraints that bind depend on the choice of qualities offered. This destroys the recursive structure of the single-dimensional case, in which one solves first for q_i and then imputes u_i from the (ex ante known) binding IC constraints. Second, in multiple dimensions one must introduce an important additional constraint called an integrability condition.[24]

The consequence of these difficulties is that multidimensional models of endogenous price and quality choice are generally intractable. Even a single additional characteristic available for screening significantly complicates matters.[25] A recent paper by Rochet and Stole (2001), however, has introduced a generalized one-dimensional screening model that keeps the tractable structure of one-dimensional models while generalizing the strong empirical predictions of such a model. We describe the basic features of this model in the next section.

3.4 The Generalized One-Dimensional Model of Rochet and Stole (2001)

Consider the standard one-dimensional model of Mussa and Rosen (1978) presented above, but modified by modeling the participation constraint as a random variable. Specifically, suppose consumers have preferences

[23] Technically, the solution described above, obtained pointwise in t, is called the solution to "The Incomplete Problem". Specifically, it ignores an additional second-order necessary condition for optimality: that $q(t)$ is non-decreasing in t, ruling out local minima. It also ignores a sufficient condition for optimality: that $t(q)$ is non-decreasing in q. The monopolist's problem with these conditions imposed is called "The Complete Problem." (Wilson, 1993, Chapter 8.1) presents a detailed discussion of the conditions under which these are likely to be violated. Specifically, he shows that the each is most likely to occur when the distribution of types is bimodal, causing the optimal tariff to cross some types' demand curves in two or more locations. These conditions can be ignored with additional assumptions commonly invoked in the theoretical literature: that the hazard rate is increasing in t (ruling out the first concern) and that $\frac{U_{qt}}{U_q}$ is decreasing in t (ruling out the second). Even when these conditions fail, one can use the "ironing" technique developed by Mussa and Rosen (1978) to find the optimal price schedule subject to the monotonicity constraint.

[24] The integrability condition requires that consumers may select any sequence of incremental purchases – incruing their corresponding marginal prices – in order to obtain the magnitude of their total tariff for an arbitrary purchase.

[25] See (Wilson, 1993, Chapter 8) and the examples in Rochet and Chone (1998).

over J alternatives and an outside alternatives given by

$$\begin{aligned} u_j(q_j, t) &= v(q_j, t) - P_j \qquad\qquad j = \{1, \ldots, J\} \\ u_0(q_0, t) &= \epsilon \end{aligned} \tag{10}$$

where t indexes a household's type, measuring their willingness-to-pay for quality, q_j indexes the aggregate quality of good j, good 0 is the outside good, with quality and price normalized to zero, and ϵ is an idiosyncratic random shock equal to the value of the outside good to individual i. Without loss of generality, one may rewrite the utility to each good j as $u_j(q_j, t) = v(q_j, t) - P_j - \epsilon$.

Comparing this model with the theoretical and empirical models surveyed earlier, note that only tastes for the outside good, 0, has an idiosyncratic random shock, ϵ. It is in this sense that there is *random participation* but not, however, *random utility*, as that would require additional taste shocks, ϵ_{ij}, associated with each good, j. This is therefore a generalization of the theoretical literature on nonlinear pricing but a special case of the empirical literature on differentiated product demand estimation.[26]

As in MR and RS, assume that preferences are linear in quality, $v(q_j, t) = tq_j$, and that costs are quadratic in quality, $C(q_j) = 0.5q_j^2$. In this case, total surplus, $S(q_j, t) \equiv tq_j - 0.5q_j^2 - \epsilon$. Let $u = \max_{q_j} tq_j - P_j$ give the indirect utility for consumer type t. Then the probability that any type she purchases from the monopolist is given by

$$M(u, t) = \text{Prob}[(\epsilon, t)|\epsilon \leq u] \tag{11}$$

M may be considered the market share function. Let the inverse hazard rate of M over u be given by $H(u, t) \equiv \frac{M(u,t)}{M_u(u,t)}$ and assume $H(u, t)$ is nondecreasing in u.

As in the MR model, Rochet and Stole (2001) consider non-random nonlinear price schedules of the form, $P(q)$ or, equivalently, direct revelation mechanisms of the form $\{q_j(t), P_j(t)\}_{t \in T}$ such that each type, t, purchases one of the J offered goods.

Profits are then given by

$$\max_{q_j(t), P_j(t)} E[\pi] = \int_t M(u(t), t)\{S(q_j(t), t) - u(t)\} \tag{12}$$

subject to incentive compatibility constraints

$$u(q_j(t), t) \geq u(q_j(t'), t) \quad \forall t' \neq t \tag{13}$$

Note that individual rationality constraints are automatically built into the firm's objective function by use of the market share function, M. Relative to expected profits in the MR model (Equation (7)), expected profits with random participation replaces the (exogenous) type probabilities, f_i, with the market share function M.

The solution of this problem depends on the structure of T (i.e. discrete v. continuous) and on the joint distribution of (ϵ, t). The discrete case is particularly tractable as in this case there may be a fully separating

[26] Extending the framework to allow for random utility is non-trivial. The difficulty arises because random utility breaks the ability to incorporate the incentive compatibility constraints directly into the objective function as described below. The one-dimensional problem with random utility therefore resembles the general, and generally intractable, multidimensional screening problem.

equilibrium yielding a one-to-one map between types and qualities. For expositional convenience, we assume this is the case for the balance of this section and index both types and products by i.

For the case of discrete types, (Rochet and Stole, 2001, Section 3) characterize the solution to this problem. They first show that, as for the MR model, if margins increase with type (a sufficient condition for which is H be nondecreasing in t), then the upward incentive compatibility constraint is always slack ((Rochet and Stole, 2001, Lemma 1)). If so, the optimal allocation will, like the MR model, exhibit no distortion at the top of the type distribution.

To say more requires more assumptions on the joint distribution of ϵ and t. If they are independent, $M(u,t) = G(u)f(t)$ (where $f(t) \equiv f_t(t_i) = f_i$) and $H(u) = \frac{G(u)}{g(u)}$, where $G(\epsilon)$ is the CDF of ϵ. Furthermore, if H is convex in u, the full monopoly solution can be characterized.

In this case, the monopolist's objective function can be written as

$$\max_{q_i, u_{i\, i=1,\ldots,N}} \pi = \sum_{i=1}^{N} f_i G(u_i)[S_i - u_i] \tag{14}$$

subject to the incentive compatability constraints $u(q_i, t_i) \geq u(q_j, t_i) \quad \forall j \neq i$. In this notation, $q_i \equiv q(t_i)$, $P_i \equiv P(t_i)$, and $S_i \equiv S(q(t_i), t_i)$.

As in the MR model, our assumptions permit solving for the minimum utility each type must receive in any equilibrium allocation (their "information rents"):

$$\begin{aligned} u(q_i, t_i) &= u(q_{i-1}, t_i) \\ &= u(q_{i-1}, t_{i-1}) + u(q_{i-1}, t_i) - u(q_{i-1}, t_{i-1}) \\ &= u(q_{i-1}, t_{i-1}) + \Delta t_{i-1} q_{i-1} \\ &= u(q_1, t_1) + \sum_{i'=1}^{i-1} \Delta t_{i'} q_{i'} \end{aligned} \tag{15}$$

where for any i, $\Delta t_i \equiv t_{i+1} - t_i$. This may be substituted back into the monopolist's objective function, yielding the unconstrained maximization problem:

$$\max_{q_i, u_{1\, i=1,\ldots,N}} \pi = \sum_{i=0}^{N} f_i G(u_1 + \sum_{i'=1}^{i-1} \Delta t_{i'} q_{i'})[S_i - u_1 - \sum_{i'=1}^{i-1} \Delta t_{i'} q_{i'}] \tag{16}$$

In the MR model, all households participate in the optimal program (for suitable values of the parameter space) and $G(u_i) = 1 \quad \forall i$. In this case, the monopolist leaves no rent to the lowest type ($u_1^{\text{mr}}(t) = 0$) and the optimal quality assignment is (as before)

$$q_i^{\text{mr}} = \left\{ \begin{array}{ll} t_N & \text{if } i = N \\ t_i - \sum_{i'=i+1}^{N} \Delta t_{i'} \frac{f_{i'}}{f_i} & \text{else} \end{array} \right\} \tag{17}$$

where "mr" stands for the Mussa-Rosen specification.

With random participation, the first-order conditions characterizing the optimal qualities and utility are similar:

$$u_1^{\text{rs}} \text{ solves } \sum_{i=1}^{N} f_i[g(u_i)(S_i - u_i) - G(u_i)] = 0$$
$$q_i^{\text{rs}} = \left\{ \begin{array}{ll} t_N & \text{if } i = N \\ t_i - \sum_{i'=i+1}^{N} \Delta t_{i'} \frac{f_{i'}}{f_i} \frac{G_{i'}}{G_i} \left(1 - \frac{g_{i'}}{G_{i'}}(S_{i'} - u_{i'})\right) & \text{else} \end{array} \right\} \tag{18}$$

where $u_i = u_1 + \sum_{i'=1}^{i-1} \Delta t_{i'} q_{i'}$.

There are several differences in the resulting equilibrium allocations. First, for the case of random participation, the monopolist has an incentive to leave rents to the lowest type, implying $u_1 \neq 0$.

There are additional differences in the equilibrium qualities. As in the MR model, there is efficiency at the top. For the remaining qualities, however, there are two additional terms in the RS model not present in the MR model, with competing effects on equilibrium quality. The first term, $\frac{G_{i'}}{G_i}$, implies that the relative probability of high versus low types is changed by random participation. Specifically, since u is increasing in type, high-types are relatively more common than in a world without random participation, inducing a greater distortion in qualities relative to that world.

The second term, $(1 - \frac{g_{i'}}{G_{i'}}(S_{i'} - u_{i'}))$, moderates quality distortions. Random participation implies the monopolist cannot extract all of the "virtual surplus" from each type (as in the standard case). Instead, when considering, e.g., a price increase for a particular type, he must now trade off increased rent extraction against lost market share from that type. Furthermore, since utilities (and thus prices) are connected by the incentive compatibility constraints, reducing prices to low types (and increasing their rents) increases market shares of *all* types. This implies the return from eliminating rents for high types with high prices to low types is lower here relative to the MR model, reducing quality distortions.

While either effect may dominate for particular parameter values, Rochet and Stole (2001) find the latter effect is stronger when types are closer. This suggests random participation likely moderates quality distortion. Verifying this finding and quantifying its magnitude, however, is an empirical issue. We address this issue after introducing the data on cable television systems used in our empirical analysis.

4 The Cable Television Industry

Cable television systems select a portfolio of programming networks, bundle them into one or more services and offer these services to households in local, geographically separate, monopoly cable markets. Systems typically offer three types of networks: broadcast networks, cable networks, and premium networks.[27]

Broadcast and cable networks are typically bundled by cable systems and offered as Basic Service. Some systems, however, elect to split up these networks and offer some portion of them as smaller bundles of networks known as Expanded Basic Services. Premium networks are typically separated into individual

[27] Broadcast networks are television signals broadcast in the local cable market and then collected and retransmitted by cable systems. Examples include the major, national broadcast networks - ABC, CBS, NBC, and FOX - as well as public and independent television stations. Cable networks are advertising-supported general and special-interest networks distributed nationally to systems via satellite, such as MTV, CNN, and ESPN. Premium networks are advertising-free entertainment networks, typically offering full-length feature films, such as HBO and Showtime.

services and sold on a stand-alone basis. Despite the presence of separate Expanded Basic and Premium Services, households may not buy them directly. They are first required to purchase Basic Service.[28]

An important feature of cable system management is their almost complete control over the content and price of service bundles. With respect to content, while certain regulations mandate they carry all broadcast television stations available over the air in their service area (so-called Must-Carry requirements), beyond these restrictions they may select and package whatever television networks they like for sale to households. With respect to prices, cable systems have been subject to cyclical regulatory oversight.[29] Most recently, the 1996 Telecommunications Act removed price controls on Expanded Basic Services, leaving only Basic Service subject to (possible, though weak) regulation.

The institutional and economic environment in the cable television industry suggests the choice of quality and price of Basic and Expanded Basic Services may map well to the theory. Since households that buy Expanded Basic Services must necessarily first purchase Basic Service, these services are by construction increasing in overall quality. Furthermore, since they consist of (generally large) bundles of individual networks, the range of qualities possibly chosen is plausibly continuous, and offered qualities are clearly discrete.[30] In the balance of the paper, we therefore focus on modeling endogenous quality choice for Basic Cable Services.

4.1 Data

We've compiled a market-level dataset on a cross-section of United States cable systems to estimate the model. The primary source of data for these systems is Warren Publishing's Television and Cable Factbook Directory of Cable Systems. The data for this paper consists of the population of cable systems recorded in the 1996 edition of the Factbook for which complete information was available.[31] From the population, a sample of 1,164 systems remained.

Table 1 present sample statistics for selected variable for these systems. In this version of the paper, we focus on simple measures of quantity (or market share), price, and quality. In future versions, we will incorporate information about household characteristics and service costs into the empirical analysis. The identities of the networks offered on cable services in particular are important determinants of the quality of offered cable services (Crawford (2000)). We disaggregate programming networks into groups according to the size of their potential audience. The top 15 cable programming networks available in the United States in 1998 are listed in Table 3.

While all systems offer a Basic Service, Table 1 shows that slightly more than a third of systems offer

[28] This is known as a tying requirement. See Whinston (1990) for a recent analysis of the strategic incentives to tie.

[29] The most recent incident of price regulation was the 1992 Cable Act, the intent of which was to limit the prices charged for Basic and Expanded Basic Services. Due to a combination of factors, including strategic responses by cable systems to the imposed regulations and relatively weak cost pass-through ("going-forward") requirements, these provided little benefit to households (Hazlett and Spitzer (1997), Crawford (2000)).

[30] In a complementary line of analysis, Crawford (2001) and Coppejans and Crawford (1999) considers the incentives to bundle networks into Basic Services. This line of work tests the *discriminatory* incentives to bundle: namely that it by reducing heterogeneity in consumer tastes, bundling implicitly sorts consumers in a manner similar to 2nd-degree price discrimination. See Armstrong (1999) and Bakos and Brynjolfsson (1999) for an exposition of the theory. This effect contrasts directly with the screening theory presented in this paper: there the monopolist *unbundles* goods to *explicitly* sort consumers. Understanding firms' incentives to bundle versus screen is an interesting area of future research.

[31] While there are over 11,000 systems in the sample, persistence in non-response over time as well as incomplete reporting of critical variables required imposing a large number of conditions in order for a system to be included in each sample. Missing information on prices, quantities, and reporting dates were responsible for the majority of the exclusions.

Expanded Basic Services. Of these, most offer just one Expanded Service. Aggregating over all Basic and Expanded Basic Services, systems typically offer almost 6 broadcast networks, more than 17 cable networks, and almost 14 other networks.

Table 2 considers cable network carriage in more detail. The 1st column reports the proportion of systems in the sample that carry each of the top-15 cable programming networks on any Basic Service. The remaining columns of the table examine the proportion of systems that carry each of the top-15 cable networks on each Basic or Expanded Basic Services. Several interesting patterns emerge. First, note that the majority of the networks are offered on *some* service by the majority of systems. Some of the most popular networks, WTBS, CNN, and ESPN are available on over 95% of all systems. Systems differ, however, in how they allocate these networks among Basic and Expanded Basic services. While some, like CSPAN and QVC, are almost exclusively offered on Basic, others, like TNT and TNN, are often found on Expanded Services. Importantly, there is significant heterogeneity both in the carriage of networks across systems, as well as in their allocation to Basic and Expanded Basic Services.

5 Empirical Specification and Results

In this section, we present a simple economic and econometric model of endogenous price and quality choice of Basic cable television services.

5.1 The Theoretical Specification

The basic theoretical model is the RS model of nonlinear pricing with random participation with discrete types and discrete qualities described in section 3.4 above. Further details of the specification idiosyncratic to the empirical model follow.

In addition to the assumptions in section 3.4, we assume that cable services can be ranked in quality, i.e. $q_1 < ... < q_n$. As lower levels of service are purchased with each higher level of cable service, it is satisfied by construction for the dataset used in this paper. For now, assume the single index q_j is observed for each j; in the econometric estimation, we will solve for the implied quality offered on each product.

For tractability, we assume that the distribution of consumer types in each markets is of the dimension of the number of products offered in that market, i.e. $m = n$, $n \leq 3$. As described earlier, this is a particularly attractive assumption in the case of discrete qualities as there may be a fully separating equilibrium yielding a one-to-one map between types and qualities. For expositional convenience, we assume this is the case for the balance of this section and index both types and products by i. Let the unconditional probability for each type be given by $f_i \equiv f_t(t_i)$ with $\sum_k^n f_t(t_k) = 1$. In the appendix, we discuss relaxing this assumption to allow for a continuous distribution of consumer types common across all markets (in process).

Assume further that ϵ and t are independent, so that $M(\epsilon, t) = G(\epsilon)f(t)$. For analytical convenience, we assume $\epsilon \sim U[0, \sigma]$, implying $G(u) = u/\sigma$ and $g(u) = 1/\sigma$.[32] Let $\theta^{rs} \equiv \{t_1, \ldots, t_n, f_1, \ldots f_{n-1}, \sigma\}$ index all the parameters known to the firm for the RS model (where f_n is implied by the other type probabilities).

In the fully separating case, market shares are simply given by the share in the population of the type

[32] We intend to explore alternative specifications in future revisions.

assigned to purchase quality, q_i:

$$\begin{aligned} s_i &= f_i G(t_i q_i - P_i) \\ &= f_i G(u_i) \end{aligned} \tag{19}$$

where $u_i \equiv u(q_i, t_i) = t_i q_i - P_i$.

The first-order conditions for optimal qualities and utility was given by Equation (18) for the RS model. These define a set of $n+1$ equations which must be solved numerically for each value of θ^{rs}. For the case of $n = 3$ and $\sigma = 1$, these are equal to

$$\begin{aligned} u_1 &= \frac{f_1 S_1 + f_2 S_2 + f_3 S_3 - 2(f_2 + f_3)\Delta t_1 q_1 - 2 f_3 \Delta t_2 q_2}{2(f_1 + f_2 + f_3)} \\ q_2 &= \frac{f_2 t_2 (u_1 + \Delta t_1 q_1) - \Delta t_2 f_3 [2(u_1 + \Delta t_1 q_1) - S_3]}{f_2 u_1 + f_2 \Delta t_1 q_1 + 2\Delta t_2^2 f_3} \\ q_1 &= \frac{f_1 t_1 u_1 - \Delta t_1 f_2 (2u_1 - S_2) - \Delta t_2 f_3 [2(u_1 + \Delta t_2 q_2) - S_3]}{f_1 u_1 + 2 f_2 \Delta t_1^2 + 2\Delta t_1 \Delta t_2 f_3} \end{aligned} \tag{20}$$

with $q_3 = t_3$. Given u_1, u_i is given by the incentive compatibility constraints as described in Equation (15). Given optimal qualities and utility, prices are given by $P_i = u_i - t_i q_i$. Figure 2 presents an example of equilibrium quality allocations for representative parameter values as we vary t_2.

We also consider estimation of the MR model. In this case, let θ_c^{mr} index the parameters of the distribution of consumer types facing the firm.[33] For any θ, qualities may be obtained analytically by Equation (17) for this model.

5.2 Econometric Specification

In our empirical analysis, we estimate both the MR model and the RS model. In each case, we consider each cable market in isolation and infer the unknown parameters of the distribution of consumer tastes by equating the market shares and prices predicted by the model to those observed in the data.

To do so, consider a cable monopolist in a market indexed by $c = 1, \ldots, C$. For each model, let θ_c index the parameters of the distribution of consumer types facing the firm. Each of the MR and RS models implies a set of market shares, $s_{jc}(\theta)$, prices, $P_{jc}(\theta)$, and qualities, $q_{jc}(\theta)$, for $j = 1, \ldots, n_c$, where n_c is the number of cable services offered in market c. Note that by assumption θ is of dimension $2n_c$.

We observe in the data market shares and prices, and (possibly) qualities. In this version of the paper, we exploit the information contained in just the market shares and prices. In future revisions, we will allow for estimation using the number and identities of the channels provided on each service as an explicit measure of quality. Let y_c index the observed endogenous variables in market c. Note that there are $2n_c$ prices and market shares in each market.

Throughout, we assume that there is no pooling over types, so that each type chooses a bundle distinct from that chosen by the other types. Given this assumption, the markets in which only two cable bundles are

[33]Note despite the presence of σ in the RS model, there are actually an equal number of parameters in both models. The reason for this is that the MR model requires another type, $t_0 = 0$ with estimated probability f_0 to account for purchases of the outside good. In the RS model, purchases of the outside good are endogenously given by the type-specific market shares.

marketed can only be explained by the fact that the taste for quality heterogeneity has only two points of support. We are currently relaxing this assumption by extending the model to an environment where the consumer type distribution is continuous.

We propose a two-step estimation procedure. In the first step, we solve the nonlinear pricing problem for the monopolist, and find values for the contracts which are consistent with the observed prices and market shares, *on a market-by-market basis.* In the second step, we regress the contract parameters obtained in step one on bundle characteristics, in order to explain the heterogeneity in observed contracts across markets.

5.3 First step

In the first step, we assume that the monopolist knows θ_c and chooses the menu of prices and qualities to maximize his profits as described by the standard model of Mussa and Rosen (1978) as well as the random participation model of Rochet and Stole (2001). The first step is performed for each market c. Therefore, in this section, we omit the subscript c for simplicity.

For the three type case, the contract parameters are:

- q_i, $i = 1, 2, 3$: quality of the bundle bought by type i
- p_i, $i = 1, 2, 3$: price of the bundle bought by type i
- u_i, $i = 1, 2, 3$: net utility obtained by type i, assuming participation

Parameters of consumer heterogeneity distributions are:

- f_i, $i = 1, 2$: mass points of 3-point taste for quality distribution[34]
- t_i, $i = 1, 2, 3$: type values
- σ: parameter(s) for the outside value distribution

In the first step, we will employ a *two-level nested routine*. In the *inner loop*, we will solve for the "fundamental" contract parameters u_1, q_1, q_2, q_3, as a function of the consumer heterogeneity parameters. These contract parameters can, in turn, be used to derive the other parameters u_2, u_3 as well as the p_i's.

For the MR model, solving for the optimal contract parameters as a function of the population heterogeneity parameters can be done analytically (using equation (17) above). For the RS model, however, there is no analytic expression for the optimal contract parameters available, and so we obtain them numerically by solving the system of equations (18). In practive, this is generally quite fast and robust to the starting values chosen for the algorithm.

In the *outer loop*, we search for values of the heterogeneity parameters $\theta \equiv \{f_1, f_2, t_1, t_2, t_3, \sigma\}$ in order to equate the predicted to observed data, i.e., to solve the following set of equations (where the hats ($\hat{\cdot}$'s) denote

[34] where $f_3 = 1 - f_1 - f_2$.

data values):

$$\begin{aligned}\hat{p}_i &= p_i,\ i=1,2,3\\ \hat{s}_i &= G(u_i;\sigma) f_i,\ i=1,2,3\\ \hat{s}_0 &= \sum_{i=1}^{3}(1-G(u_i;\sigma)) f_i.\end{aligned} \tag{21}$$

Given only six equations, we can only estimate at most six parameters, which restricts G, the population distribution of reservation values, to be from a single-parameter family. In our empirical work, we use $G(x;\sigma)=\frac{x}{\sigma}$ (i.e., a uniform distribution on $[0,\sigma]$).[35] Let optimal values of θ be denoted with stars (*'s).

5.4 Second step

In the first step, we have obtained values of q^*_{ic}, t^*_{ic}, and f^*_{ic} for all markets c. In the second step, we can run a regression of q^*_{ic} on bundle characteristics (we refer to these covariates collectively as X_{ic}) to try and explain the heterogeneity in observed contracts across markets. For example, to explain how the quality of the bundle varies depending on the components of the bundle, we can run the following regressions:

$$q^*_{ic} = \beta'_i X_{ic} + \epsilon_{ic},\ \forall i,n \tag{22}$$

where X_{ic} consists of the characteristics of the i-th bundle in market c (including dummy variables for the more important cable channels in the bundle).

Equation (22) can be interpreted in two ways. First, we can interpret it just as a restriction that the conditional (on Z) expectation of q^* is linear, so that $E[q^*|X_{ic}]=\beta'_i X_{ic}$, so that the residuals ϵ_{ic} represent pure prediction error which by construction satisfies the orthogonality restriction $E[\epsilon|X_{ic}]=0$. With this interpretation, the coefficients β cannot be interpreted as the causal effects of changes in X_{ic} on perceived quality q^*. These coefficients would be of limited use in counterfactual experiments, when one wished to simulate the equilibrium effects of changes in bundle composition.

On the other hand, one way wish to interpret equation (22) as a structural equation which posits a deterministic relation between (X_{ic},ϵ_{ic}) and perceived quality q^*_{ic}. Here, (X_{ic},ϵ_{ic}) are (resp.) the observed and unobserved characteristics of the i-th bundle in market c. In this case, a consistent estimate of β can be interpreted as the causal effect of changes in X_{ic} on perceived quality q^*. However, in this case, we obtain a consistent estimate of the structural parameter β via regressing q^* on X only when $E[\epsilon_{ic}|X_{ic}]=0$ (i.e., X is "exogenous"). When this orthogonality restriction does not hold, we must find appropriate instruments Z_{ic} so that $E[\epsilon_{ic}|Z_{ic}]=0$. Candidate instruments should, roughly speaking, be correlated with the observed characteristics X_{ic} but uncorrelated with the unobserved characteristics (or "unobserved quality"). If we interpret ϵ_{ic} as market c's idiosyncratic valuations for the components in bundle i, then appropriate instru-

[35] For markets with more than one service, this outer loop requires numerical solutions to the system of nonlinear equations (21). In practive, we did this in Matlab using the 'fsolve' command which uses a combination of Gauss-Newton and Levenberg-Marquardt algorithms on the implied sum-of-squares problem. This is much less robust, often getting stuck at a minimum that is not a root, and depends on having good starting values. Indeed, the algorithm converged for 72 of 168 3-good markets and 240 of 266 2-good markets. The current estimation dataset therefore contains 1042 of the 1164 initial observations.

The existing numerical methods we are using are somewhat crude and not the preferred techniques. Experimentation with more sophisticated solution techniques for nonlinear systems of equations (e.g. Powell's method or homotopy methods) shows promise of improving the yield.

ments could perhaps be the $X_{ic'}$ in markets c' which are either close to market n, or served by the same cable provider which serves market n (cf. Crawford (2001)).

There are some interesting similarities between our two-step estimation algorithm and the multi-step algorithm develop in Berry (1994) and Berry, Levinsohn, and Pakes (1995a) (BLP) for estimating discrete-choice models of demand in differentiated product markets with only data on aggregate market shares. In both cases, one obtains the dependent variables for the second stage regressions by "solving" a set of population nonlinear equations in the first stage. In the BLP case, the demand (market share) equations are solved for the "mean utility" parameters δ_j corresponding to each product j, whereas in our case, both the demand as well as supply equations are used to solve for the quality (the q's) and heterogeneity (the t's and f's) parameters. In both cases, there is no "estimation" in the first step (i.e., there is no standard error for the parameters derived in the first step).

On the other hand, one important differences between our estimation algorithm and the BLP algorithm concerns the asymptotics: in the simplest, cross-sectional version of BLP, the asymptotic inference relies on J, the number of products, diverging to infinity, whereas in our model, the asymptotics are in N, the number of markets.

Furthermore, the current econometric model has no sources of error in demand or cost, as well as no observable heterogeneity in demand or cost conditions. These are strong assumptions that we intend to relax in future revisions. The existing estimates are intended to provide an example of the types of results we expect to get with a more general empirical specification.

5.5 Results

The results of the econometric estimation yield two matrices of demand parameters: θ_c^{mr} and θ_c^{rs}, for $c = 1, \ldots, C$. Tables 4 and 5 report the estimates of these fundamental parameters, as well as the resulting qualities, utilities, and profits implied by their values.

Our first results compare the output of the MR and RS models. Table 4 reports the estimated value of the type parameters, t_i, associated probabilities, f_i, and implied qualities for each of the models for markets with 3, 2, and 1 Basic services. Also reported are the deviations in the estimated qualities from first-best qualities, $q_i^{\mathrm{fb}} = t_i$.

As can be seen in Table 4, the MR model has a difficult time matching observed prices and market shares. In particular, for the parameters equating prices and market shares, average qualities are predicted to be *negative*. This of course violates individual rationality in the MR model, suggesting these goods wouldn't be offered in equilibrium. This logical inconsistency implies that given our assumptions, the data reject the MR model.

By contrast, the RS model with random participation has no difficulties rationalizing the data. Willingness-to-pay for quality is estimated to be higher and there is significantly less quality degradation than that predicted by the MR model. That having been said, there is still a significant amount of quality degradation in the RS model. Offered quality is an estimated 8% and 16% less in 3-good markets and 31% less in 2-good markets.

What impact does this quality degradation have on consumer and social welfare? By identifying the structure of preferences and costs, we may not only report the implied quality provided by firms, but also simulate the profit and welfare consequences of alternative portfolios of offered qualities. We therefore consider the following simple counterfactual: we set qualities at their first-best levels and let firms choose prices to satisfy incentive compatibility and individual rationality given the estimated type distribution.

The results of this exercise are shown in Table 5. Note in one-good markets that since quality is at its first-best level in the RS model, there is no impact of the proposed change. This contrasts with the effects in two- and three-good markets. An interesting result is that while firms are necessarily worse off in these markets, consumers are only sometimes better off (as in 2-good, but not 3-good markets). Society as a whole, however, is estimated to be worse off. This is driven by the decision by firms in some markets to not offer low-quality goods when they are constrained to the first-best level.[36] As in many price discrimination problems, our results suggest the welfare consequences of endogenous product quality depends on the structure of tastes and costs in cable markets.

Finally, Table 6 reports the results of the 2nd-stage quality regressions described in the last subsection. Reported are teh parameter estimates from a Seemingly Unrelated Regression of implied qualities on the top-15 cable networks reported in Table 3. On the assumption this is a structural equation, also repored are the implied mean willingness-to-pay for each each network (using the average for high-value types, t_3). For comparison purposes, we also report the estimated mean WTP for networks reported in Crawford (2000) using the canonical empirical specification on a very similar dataset.

Two features of these results are interesting. First, the implied relationship between networks and quality are generally quite reasonable in sign and magnitude. 11 of 15 are positive and significant, with mean WTP between \$0.34 and \$3.66 (for ESPN). Additonal networks outside the top-15 are valued at \$0.23 each. Second, there are important differences between the reported estimates and those we found earlier in Crawford (2000). The estimates there were occasionally negative and generally larger in absolute value. While firm conclusions are not warranted due to differences in econometric assumptions, these results suggest controlling for endogenous quality may be important for the consistent measurement of consumer tastes in differentiated product markets.

6 Conclusions and Extensions

The purpose of this paper is to introduce an empirical framework for the analysis of endogenous quality choice in product markets. It is based on a model of nonlinear pricing with random participation recently developed by Rochet and Stole (2001). Preliminary results favor this model over the standard model of monopoly quality choice of Mussa and Rosen (1978) and suggest moderate degrees of quality degradation relative to first-best levels. This suggests existing empirical applications of models of incomplete information may overestimate the impact of information on firm behavior.

Several extensions of the existing analysis are suggested. First, while the existing specification flexibly estimates the distribution of consumer tastes in each cable market, it does not admit controlling for observed or unobserved heterogeneity in cost and demand. Furthermore, the model may be extended to allow for a

[36] This happens in 25% of 3-good markets and 58% of 2-good markets.

continuous distribution of consumer types in the presence of discrete qualities. These extensions will permit greater confidence in the estimated effects of endogenous quality, as well as quantifying its consequence on existing approaches that ignore these effects and measuring the profit losses from a discrete versus fully continuous quality menu.

More broadly, we hope by extending commonly applied empirical models to consider quality choice, we may expand the set of empirical research questions analyzed in Industrial Organization. For example, issues of entry deterrence and collusive market allocation might profitably be analyzed with these techniques. Further extensions of the theory of screening contracts to accommodate the realities of empirical work would also be welcome and could further extend the model's applicability.

Table 1: Sample Statistics
Selected Characteristics

Variable	All Markets	3-Good Markets	2-Good Markets	1-Good Markets
Expanded Basic Services				
Any Exp. Basic Svcs.	0.37	1.00	1.00	0.00
One Exp. Basic Svc.	0.23	0.00	1.00	0.00
Two Exp. Basic Svcs.	0.14	1.00	0.00	0.00
Market Shares				
w_3	0.65	0.52	0.61	0.70
w_2	0.02	0.10	0.04	—
w_1	0.00	0.02	—	—
Prices				
p_3	20.84	25.53	22.55	19.13
p_2	5.83	21.21	12.13	—
p_1	2.55	17.64	—	—
Programming				
Cable Networks				
q_3	17.11	22.56	20.65	14.57
q_2	4.09	17.99	6.53	—
q_1	1.89	13.10	—	—
Broadcast Networks				
Over-the-Air	2.60	3.28	2.81	2.37
On Cable	5.84	6.73	6.47	5.40
Other Networks on Basic	13.90	10.36	12.88	15.09
Observations	1164	168	266	730

Table 2: Sample Statistics
Top-15 Networks

Services	**Any Basic**	**Basic**	**Expanded Basic I**	**Expanded Basic II**
TBS	0.98	0.77	0.10	0.11
Discovery	0.83	0.54	0.24	0.05
ESPN	0.98	0.79	0.19	0.01
USA Network	0.87	0.60	0.26	0.02
C-SPAN	0.42	0.36	0.06	0.00
Top-5	4.09	3.05	0.85	0.18
TNT	0.81	0.55	0.20	0.06
Family	0.92	0.69	0.19	0.04
TNN	0.93	0.63	0.25	0.06
Lifetime	0.51	0.36	0.15	0.00
CNN	0.96	0.67	0.25	0.04
Top-10	8.22	5.94	1.89	0.39
A&E	0.52	0.39	0.13	0.00
Weather	0.47	0.30	0.15	0.02
QVC	0.51	0.47	0.04	0.00
TLC	0.24	0.19	0.05	0.00
MTV	0.51	0.38	0.13	0.00
Top-15	10.46	7.66	2.38	0.42
Other Cable Nets.	6.66	4.84	1.53	0.29
Total Cable Nets.	17.12	12.50	3.91	0.71

Table 3: Top-15 Cable Programming Networks

Rank	**Network**	**Subscribers (millions)**	**Proramming Format**
1	TBS Superstation	77.0	General Interest
2	Discovery Channel	76.4	Nature
3	ESPN	76.2	Sports
4	USA Network	75.8	General Interest
5	C-SPAN	75.7	Public Affairs
6	TNT	75.6	General Interest
7	FOX Family Channel	74.0	General Interest/Kids
8	TNN (The Nashville Network)	74.0	General Interest/Country
9	Lifetime Television	73.4	Women's
10	CNN (Cable News Network)	73.0	News
11	A&E	73.0	General Interest
12	The Weather Channel	72.0	Weather
13	QVC	70.1	Home Shopping
14	The Learning Channel (TLC)	70.0	Science
15	MTV: Music Television	69.4	Music

Source: NCTA (1998).

Table 4: Results from the MR and RS Models

	3-Good Markets		2-Good Markets		1-Good Markets	
Variable	MR	RS	MR	RS	MR	RS
Type Distribution						
t_3	4.15	5.45	4.48	5.03	4.35	6.04
t_2	3.92	5.20	4.34	4.24	—	—
t_1	3.41	4.53	—	—	—	—
f_0^{mr}	0.37	—	0.35	—	0.30	—
σ	—	3.89	—	3.85	—	27.12
f_3	0.47	0.58	0.61	0.84	0.70	1.00
f_2	0.12	0.19	0.04	0.16	—	—
f_1	0.04	0.23	—	—	—	—
Qualities						
q_3	4.15	5.45	4.48	5.03	4.35	6.04
$\frac{t_3-q_3}{t_3}$	0.00	0.00	0.00	0.00	0.00	0.00
q_2	-2.31	4.76	-1.47	2.95	—	—
$\frac{t_2-q_2}{t_2}$	-20.56	0.08	-27.55	0.31	—	—
q_1	-3.25	3.79	—	—	—	—
$\frac{t_1-q_1}{t_1}$	-27.71	0.16	—	—	—	—
Observations	72	72	240	240	730	730

Table 5: Estimated and First-Best Outcomes

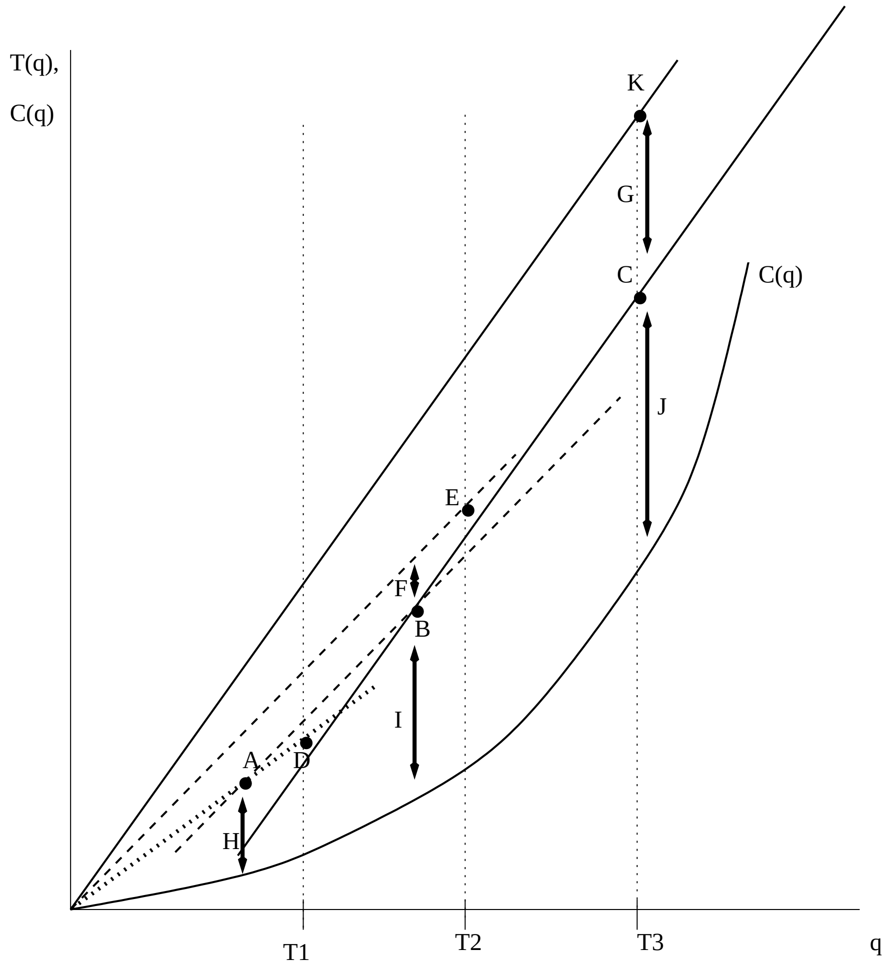
	3-Good Markets		2-Good Markets		1-Good Markets	
Variable	RS	FB	RS	FB	RS	FB
q_3	5.45	5.45	5.03	5.03	6.04	6.04
$\frac{t_3-q_3}{t_3}$	0.00	0.00	0.00	0.00	0.00	0.00
q_2	4.76	5.20	2.95	4.24	—	—
$\frac{t_2-q_2}{t_2}$	0.08	0.00	0.31	0.00	—	—
q_1	3.79	4.53	—	—	—	—
$\frac{t_1-q_1}{t_1}$	0.16	0.00	—	—	—	—
u	2.83	2.73	2.49	6.06	17.73	17.73
π	10.39	10.05	9.46	5.32	0.70	0.70
s	13.22	12.73	11.95	11.36	18.43	18.43
Observations	72	72	240	240	730	730

Table 6: Parameter Estimates

Cable Programming Parameters

Variable	Estimate (StdErr)	Implied Mean WTP	Crawford (2000) Mean WTP
WTBS	0.01	0.07	0.93
	(0.02)		
Discovery	0.12	0.67	-0.39
	(0.03)		
ESPN	0.63	3.66	5.50
	(0.03)		
USA	0.14	0.79	0.91
	(0.02)		
CSPAN	-0.01	-0.08	—
	(0.02)		
TNT	0.03	0.19	-0.38
	(0.03)		
Family	0.25	1.45	-1.22
	(0.02)		
Nashville	0.07	0.38	-0.53
	(0.02)		
Lifetime	0.06	0.34	—
	(0.02)		
CNN	0.11	0.63	-0.39
	(0.02)		
A&E	0.23	1.33	—
	(0.02)		
Weather	-0.07	-0.40	—
	(0.02)		
QVC	0.22	1.25	—
	(0.03)		
Learning	0.09	0.52	—
	(0.02)		
MTV	0.09	0.55	0.19
	(0.02)		
Other Nets.	0.04	0.23	0.10
	(0.00)		

Figure 1: Illustration: Nonlinear Pricing and Quality Degradation



Solid lines represent indifference curves for Type 3 in (T, q) space.[a]
Dashed lines represent indifference curves for Type 2 in (T, q) space.
Dotted lines represent indifference curves for Type 1 in (T, q) space.

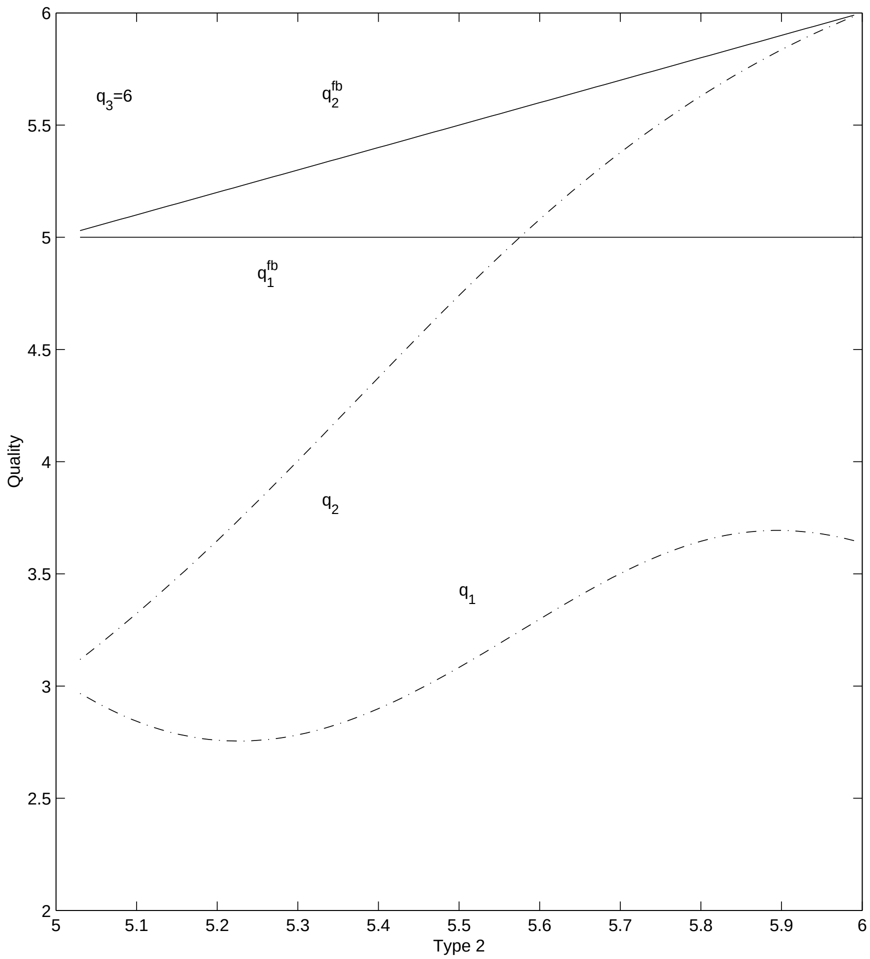
A, B, C: (q, T) allocations in the optimal nonlinear contract for (resp.) types 1, 2, 3
D, E, K: socially optimal (q, T) allocations (feasible only under perfect price discrimination). At these points, $U'(q) = C'(q) \Leftrightarrow t_i = q_i,\ i = 1, 2, 3.$

F, G: Informational rents for Types 2 and 3, in optimal nonlinear tariff.

H, I, J: Profits for monopolist from selling to (resp.) Types 1, 2, and 3.

[a] Utility is increasing towards to "southeast". Indifference curves through the origin represent a zero utility level (i.e., binding IR constraint).

Figure 2:



6
5.5
5
4.5
4
3.5
3
2.5
2
Quality
5
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6
Type 2
q3=6
q2fb
q1fb
q2
q1

A Price and quality choice with continuous types, but discrete quality levels (preliminary)

In this appendix, we briefly describe a model of optimal product choice for a monopolist constrained to offer discrete bundles but faces a continuous distribution of consumer types. In future versions of this paper, we plan to extend our empirical work to accommodate a model similar to the one described in this appendix.

As for the case of discrete qualities and discrete types, suppose consumers have preferences described by Equation (10). Here, however, let types be disctributed continuously, with F_t the population CDF of t, and let $[0, \bar{t}]$ denote the support of t.[37]

In order to derive the monopolist's optimal quality/price choice problem, we need to derive the demand functions. Given this structure, demand is characterized by "cutoff" points. More specifically, we can define "indifferent consumers" $\tilde{t}_i,\ i = 1, \ldots, m$ so that consumer $\tilde{t}_i$ is indifferent between bundle i and bundle $i-1$. Note that all consumers with $t < \tilde{t}_1$ choose the outside good.

Given the utility specification, the cutoff points are defined by the indifference conditions:

$$\begin{aligned} q_3\tilde{t}_3 - p_3 =& q_2\tilde{t}_3 - p_2 \\ q_2\tilde{t}_2 - p_2 =& q_2\tilde{t}_2 - p_1 \\ q_1\tilde{t}_1 - p_1 =& 0 \end{aligned}$$

or, equivalently,

$$\begin{aligned} \tilde{t}_3 =& \frac{p_3 - p_2}{q_3 - q_2} \\ \tilde{t}_2 =& \frac{p_2 - p_1}{q_2 - q_1} \\ \tilde{t}_1 =& \frac{p_1}{q_1}. \end{aligned} \tag{23}$$

where we have assumed that the price and quality of the outside good are zero and observed prices and qualities are measured relative to the outside good.

Given this structure, the market shares for each good is just the measure of the "segment" along which consumers choose that good:

$$\begin{aligned} \tilde{f}_3 = 1 - F(\tilde{t}_3) = 1 - F\left(\frac{p_3 - p_2}{q_3 - q_2}\right) \\ \tilde{f}_2 = F(\tilde{t}_3) - F(\tilde{t}_2) = 1 - \tilde{f}_3 - F\left(\frac{p_2 - p_1}{q_2 - q_1}\right) \\ \tilde{f}_1 = F(\tilde{t}_2) - F(\tilde{t}_1) = 1 - \tilde{f}_3 - \tilde{f}_2 - F\left(\frac{p_1}{q_1}\right) \\ \tilde{f}_0 = F(\tilde{t}_1) = 1 - \tilde{f}_3 - \tilde{f}_2 - \tilde{f}_1 \end{aligned} \tag{24}$$

Now the monopolist chooses (q_j, p_j), $j = 1, \ldots, n$ to maximize its profits

$$\max_{q_j, u_{j\, j=1,\ldots,n}} \pi = \sum_{j=1}^{n} \tilde{f}_j G(u_j)[S_j - u_j] \tag{25}$$

[37] Setting the lower bound of the support to zero is a normalization.

Note the only difference between the objective function for the discrete/continuous case and the discrete/discrete case analyzed in section 3.4 is the presence of $\tilde{f}$ versus f. In the latter case, the set of types is exogenous, while in the former case it is endogenously determined by the choice of qualities and prices.

Solving the continuous type case: a "dual" approach It turns out that solving the continuous type case can be simplified by using a "dual" approach. Note that, if we fix the cutoff points t_1, t_2, and t_3 (and, therefore, set $f_1 \equiv F(t_2) - F(t_1)$, $f_2 \equiv F(t_3) - F(t_2)$, $f_3 = 1 - F(t_3)$), the profit-maximization problem facing the monopolist is identical to the problem of optimal nonlinear pricing to the discrete distribution $\{f_i, t_i\}_{i=1}^3$, where the "indifference conditions" characterizing the cutoff types t_1, t_2, t_3 are identical to the incentive compatibility conditions for the discrete type case.

This fundamental insight allows to specify a two-level nested algorithm to solve for the optimal prices and qualities for the continuous-type/discrete-bundles case. In the outer loop, we loop over values of t_1, t_2, t_3 in order to maximize equation (25) above. In the inner loop, given the current values of the t's and the accompanying f's, we can solve for the optimal contract as in the discrete-type case, described in the previous section.

It remains to generalize the econometric estimation to incorporate this extension to the theoretical model.

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