The Welfare Effects of Endogenous Quality Choice: The Case of Cable Television*

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Abstract

The purpose of this paper is to measure the econometric and economic consequences of endogenous quality choice by a multiproduct monopolist. 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 apply the generalized one-dimensional screening model of Rochet and Stole (2002) to analyze price and quality choice for Basic cable television services. Our results suggest significant degradation in product quality relative to first-best levels, the consumer and social welfare consequences of which appear to be roughly half that from monopoly pricing.

*** Preliminary. Comments welcome. Please do not cite or quote. ***

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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 equilibrium 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. Furthermore, 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 private and social incentives to introduce new products, an important issue for investment and competition policy.

The purpose of this paper is to measure the econometric and economic consequences of endogenous 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.

Using the screening approach is surprisingly useful, as it both (1) provides a set of well-developed analytical techniques for finding equilibria with endogenous prices and qualities and (2) delineates the set of problems that may tractably be solved. The latter result is superficially negative, as solving for endogenous prices and qualities quickly becomes difficult for the class of preferences commonly assumed in empirical 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 typically difficult undertaking for all but a very small set of special cases.[5] That the set of products offered by (most) firms is discrete, however, ameliorates things considerably. Even when consumer preferences are continuous, product

[1]Examples include the seminal work of Trajtenberg (1989) in health care technology, Petrin (2003) 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.

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

discreteness yields a range of more manageable problems.

In this paper, we build an empirical model based on the generalized one-dimensional screening model recently introduced by Rochet and Stole (2002) and apply it to analyze the optimal price and quality choice for Basic cable television services. Cable television is an attractive industry in which to analyze endogenous quality choice for a number of reasons. First, in any given cable market, Basic cable services differ only in the number and quality of networks offered to consumers in a *cumulative* way. A (generalized) one-dimensional model of consumer preferences is therefore sufficient. Second, there are a large number of cable systems, the vast majority of which are unregulated multi-product monopolists in their local service area in the period we study.[6] 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. Finally, as measured by the number and identity of television networks offered, there is considerable variability in service quality across systems.

The primary advantage of our approach is that we can accurately measure of the welfare benefits of price *and* quality changes. Spence (1975) showed that a single-good monopolist may either over- or under-provide quality depending on how consumers' willingness-to-pay (WTP) varies with quality for the marginal versus average consumer and the extent to which the monopolist restricts output. Mussa and Rosen (1978) showed that a monopolist offering a price-quality schedule will typically degrade product quality to all but the highest-quality good. This introduces a "quality markup" analogous to the price-cost markup from reduced quantity measuring the extent to which the change in WTP with respect to quality exceeds the change in marginal (quantity) cost with respect to quality. We believe our paper is the first to measure these effects and quantify their importance for consumer and social welfare.

Our preliminary results appear reasonable: estimated willingness-to-pay for quality is higher and more tightly distributed in markets offering more goods[7] and offered qualities implied by these estimates (as measured by the networks provided on each cable service) are (weakly) more plausible than previous results that ignore endogenous quality choice. We find moderate degradation in product quality relative to first-best levels: offered quality is an estimated 5% and 24% less in 3-good markets and 23% less in 2-good markets for households just indifferent between purchasing each good and the good of the next lowest quality (the "marginal" household).[8] The "quality markup" implied by this degradation averages between 14 and 21% for low- and medium-quality goods, less than half of the estimated price-cost markup.

To further assess the consequences of endogenous quality, we compare the average consumers surplus, firm profit, and total surplus from our baseline results with two counterfactuals: one with qualities fixed at that set by the multiproduct monopolist but with prices equal to marginal costs at that quality and another with qualities set at the efficient level but allowing monopoly pricing. While not realistic counterfactuals for policy purposes, these are useful in describing the relative importance of monopoly pricing versus monopoly quality choice is driving welfare outcomes. Indeed we find that monopoly quality choice can be quite important: total surplus increases by 3.3/55.7/53.7% in (1/2/3)-good markets from efficient pricing given monopoly

[6] 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.

[7] A result consistent with the bundling of networks into services by cable systems (Armstrong (1999b), Bakos and Brynjolfsson (1999), Crawford (2005b)).

[8] This is a lower bound on the average degradation for all households.

qualities and by -2.4/62.1/15.1% from monopoly pricing at efficient qualities.[9]

This paper is related to several empirical literatures. The first examines whether observed prices or markups can be justified by cost differences or are evidence of quality-based price discrimination (Verboven (2002), Leslie (2004), Clerides (2002)). Closest to our work in this area is McManus (2001), who estimates demand and compares marginal revenue to (observed) marginal costs to test the implications of the Mussa-Rosen model ("no distortion at the top") in retail coffee stores. By contrast, we take the theory as a maintained assumption and assess its implications for the efficiency and welfare consequences of offered qualities. The second literature analyzes the entry and product choices of firms (Bresnahan and Reiss (1987), Berry (1992), Mazzeo (2000)). Here we differ in methodology and focus. On method, we rely on information provided by the offered prices, quantities, and qualities against the reduced-form profits typically used as arguments in the entry literatures. Similarly, while the typical focus of papers in this area is on the impact of new product or firm entry on aspects of competitive interaction, we address the economic consequences of quality choice under monopoly. Methodologically, our work is closest to empirical research applying principal-agent models of adverse selection, typically in the context of nonlinear pricing (Ivaldi and Martimort (1994), Wolak (1994), Miravete (2002), Miravete and Roller (2003)). Ours is the first, we believe, to apply this to firms' choice of product characteristics and/or quality.

The rest of this paper is organized as follows. In the next section, we describe the problems posed by endogenous quality for econometric and economic inferences in the empirical analysis of 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. Section 6 presents the results and section 7 concludes.

2 Quality Choice Under Single-Product Monopoly

[This section remains to be written. Describe results from Spence (1975).]

3 Screening Models of Optimal Quality Choice

To optimally solve for both prices and quality, we apply screening models of optimal quality choice. To fix ideas, we first present the canonical Mussa and Rosen (1978) model of endogenous quality choice. We then extend it to the generalized one-dimensional model of Rochet and Stole (2002) used in our empirical work.

3.1 The Mussa-Rosen Model

Consider a multi-product monopolist in market n selling a portfolio of $j = 1, \ldots, J_n$ goods with a single dimension of quality, $q \equiv \{q_{1n}, \ldots, q_{J_n}\}$, whose qualities (or characteristics) can be freely varied over Q_n, the non-negative orthant of J_n-dimensional Euclidean space.[10] The monopolist is assumed not to be able to

[9]The discrepancy between the markup and welfare figures for these preliminary results appear to be driven by large welfare gains to consumers with extreme tastes for quality, a common problem arising when using distributions of preferences with unbounded support (e.g. Petrin (2003)). We will explore this issue further in subsequent revisions.

[10]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

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, $P(q)$.[11]

To fix ideas, suppose that consumers are differentiated by a *discrete* type parameter, $t_{in} \in \{\bar{t}_{0n}, \bar{t}_{1n}, \ldots, \bar{t}_{J_n}\}$, defined over the $J_n + 1$ products (including the outside good) with respective probabilities, f_{in}, known to the monopolist. Note this implies the monopolist offers a single quality variant per consumer type, $\bar{t}_{jn}$. Later we show how to relax this assumption and allow arbitrary continuous distributions of consumer preferences for quality. Let the associated cumulative distribution function be $F_{kn} \equiv \sum_{i=1}^{k} f_{in}$.

Let preferences be given by

$$u_{ijn} = t_{in} q_{jn} - p_{jn} \tag{1}$$

where q_{jn} = quality of product j in market n, p_{jn} = price of product j in market n, and t_{in} = (heterogeneous) individual willingness-to-pay (WTP) for quality in market n.[12] Furthermore, assume the cost function is smooth, non-decreasing, convex, and has the following form,

$$C_{jn}(q_n, Q_n) = c_{jn}(q_{jn}) Q_{jn} - C \tag{2}$$

where q_{jn} is the quality of product j in market n, Q_{jn} is the quantity of product j in market n, and C are fixed costs. Note this specification assumes that marginal costs are constant in quantity and increasing in quality and that there are no economies of scope.

In this framework, the monopolist would like to base his tariff on a consumers type (WTP for quality), but cannot as this 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).[13] 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:

$$u(q_{jn}, t_{jn}) - p_{jn} \geq u(q_{kn}, t_{kn}) - p_{kn} \quad \forall j, k \tag{3}$$

where $j, k \in \{0, \ldots, J_n\}$.

details and a more general exposition of this framework.

[11] 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.

[12] Note the canonical demand model presented earlier falls into this framework if we (1) assume homogenous taste for characteristics, $\beta_{in} = \beta$ and introduce a linear quality index, $q_{jn} = x'_{jn}\beta + \xi_{jn}$, (2) treat MU of income as willingness-to-pay for quality, $t_{in} = \frac{1}{\alpha_{in}}$, and (3) Drop random utility, $\epsilon_{ijn} \equiv 0$. We consider the implications of these differences later in this section.

[13] 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.

Given the framework above, we may specify the firm's optimization problem as

$$\begin{aligned}
\max_{p(q_{jn})} E[\pi_n] &= \sum_{j=1}^{J_n} \{p(q_{jn}) - c(q_{jn})\} Q_{jn} \\
&= \sum_{j=1}^{J_n} M_n f_{jn} \{p(q_{jn}) - c(q_{jn})\} \\
\Leftrightarrow \max_{u(q_{jn})} E[\pi_n] &= \sum_{j=1}^{J_n} M_n f_{jn} \{S(q_{jn}) - u(q_{jn})\}
\end{aligned}$$

subject to the incentive compatibility and individual rationality constraints (3) above, where π_n measures profits in market n and $S(q_{jn})$ is total surplus from good j.

Moving from the second to the third line in the expected profit is a common trick from the screening literature that notes that a firm's (variable) profits may simply be written as the difference between total and consumers surplus.[14] 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. Note also that the incentive compatibility and individual rationality constraints are the same as the market share conditions commonly used in the empirical demand literature (e.g. Berry, Levinsohn, and Pakes (1995)).

As we will see in the following examples, solving the problem in utility-quality space instead of price-quality space provides an unexpected benefit: under standard assumptions, it allows us to use the IC and IR constraints to solve for utility as a function of quality. This reduces the dimensionality of the problem and facilitates finding an equilibrium.

By the Revelation Principle, the monopolist's problem may be solved by maximizing profits over all incentive compatible and individually rational mechanisms, $\{q_{jn}, P_{jn}\}_{t \in T}$ (Fudenberg and Tirole (1991, Chapter 7)). Without loss of generality, we can solve for the optimal tariff, $p(q_{jn})$, by dividing the problem into two component parts: (1) finding an optimal assignment, $q(t_{jn})$, of qualities to types and (2) finding an optimal transfer of net benefits to types, with associated prices, $p(t_{jn})$.

Equlibrium of the Mussa-Rosen Model The results of the previous subsection are fairly general. In what follows we impose some of the additional Mussa and Rosen (1978) assumptions to build intuition about features of equilibrium in the MR model.

First, costs are assumed to be quadratic in quality, $C(q_{jn}) = \frac{1}{2} q_{jn}^2$. This implies that the total surplus from an offered product takes a convenient form:

$$\begin{aligned}
S\left(q_{jn}, t_{jn}\right) &= v\left(q_{jn}, t_{jn}\right) - C(q_{jn}) \\
&= t_{jn} q_{jn} - \frac{1}{2} q_{jn}^2
\end{aligned} \tag{4}$$

[14] The intuition is straightforward. Rather than thinking of setting prices to marginal costs plus a markup, a discriminating monopolist thinks of setting prices to the utility (surplus) of each consumer less an informational rent, i.e. rewriting equation (1) yields $p_{jn} = t_{jn} q_{jn} - u_{jn}$. Then $p_{jn} - c(q_{jn}) = t_{jn} q_{jn} - c(q_{jn}) - u_{jn} = S(q_{jn}) - u_{jn}$.

Second, we impose an important auxiliary condition on consumers utility functions is often imposed to facilitate finding equilibrium. This is the well-known "Single-Crossing Property" requiring that $u_{qt} \equiv \partial u_{ijn}/\partial q_{jn}\partial t_{in}$ 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.

Recall the monopolists profit may be written as

$$\begin{aligned} \max_{p_{jn},q_{jn}} E[\pi_n] &= \sum_{j=1}^{J_n} f_{jn}\{p_{jn} - c(q_{jn})\} \\ \Leftrightarrow \max_{u_{jn},q_{jn}} E[\pi_n] &= \sum_{j=1}^{J_n} f_{jn}\{S(q_{jn}) - u_{jn}\} \end{aligned} \tag{5}$$

subject to incentive compatibility ($u_{jn} \geq 0$) and individual rationality ($u_{jn} \geq u_{kn}, \forall k \neq j$) constraints.

Single-crossing and the maximization of profit imply that only the adjacent incentive compatibility constraints bind, i.e. the monopolist need only worry that the type assigned quality q_{jn} does not wish to purchase that assigned quality $q_{j-1,n}$. Given the structure of the problem, the utility to each type can be solved recursively as a function of the utility to the lowest type, u_{1n}, the quality offered to all lower types, and differences in the distribution of types:

$$\begin{aligned} u_{jn} &= u(q_{j-1,n}, t_{jn}) \\ &= u_{j-1,n} + \Delta t_{j-1,n} q_{j-1,n} \\ &= u_{1n} + \sum_{j'=1}^{j-1} \Delta t_{j'n} q_{j'n} \end{aligned} \tag{6}$$

where $\Delta t_{jn} \equiv t_{j+1,n} - t_{jn}$.

Using these to replace u_i in the objective function yields the unconstrained problem as a function of (only) q_{jn} and u_{1n}:

$$\max_{q_{jn},u_{1n}} E[\pi_n] = \sum_{j=1}^{J_n} f_{jn}\{S(q_{jn}) - \frac{1-F_{jn}}{f_{jn}} \Delta t_{jn} q_{jn} - u_{1n}\} \tag{7}$$

where u_{1n} is the utility of the lowest type and $\frac{1-F_{jn}}{f_{jn}}$ is the inverse of the hazard rate.[15] This 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.

Note in particular the difference between the objective functions in equations (5) and (7). The former requires solving for each offered quality, q_{jn}, as well as the utility associated with that quality, $u_{jn} \equiv u(q_{jn})$,

[15] 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.

subject to the IC and IR constraints. After substituting those constraints into the objective function, as in the latter case, firms need only select qualities and the utility to the lowest type.

This problem may easily be solved by setting the utility of the lowest type to zero, $u_{1n} = 0$, and maximizing the resulting unconstrained objective function w.r.t. q_{jn}. This solution satisfies

$$S_q(q_{jn}, t_{jn}) = \frac{1 - F_{jn}}{f_{jn}} \Delta t_{jn} \tag{8}$$

for $j = 1, \ldots, J_n - 1$, with q_{J_n} given by the solution to $S_q(q_{J_n}, t_{jn}) = 0$. The latter result implies there is "no distortion at the top," a common result in incentive theory.[16] Given optimal qualities and utility to the lowest type, utilities to all other types follow from the IR and IC constraints (6) and prices given optimal qualities and utilities are given by an inversion of the preferences equation (1), $p_{jn} = t_{jn}q_{jn} - u_{jn}$.

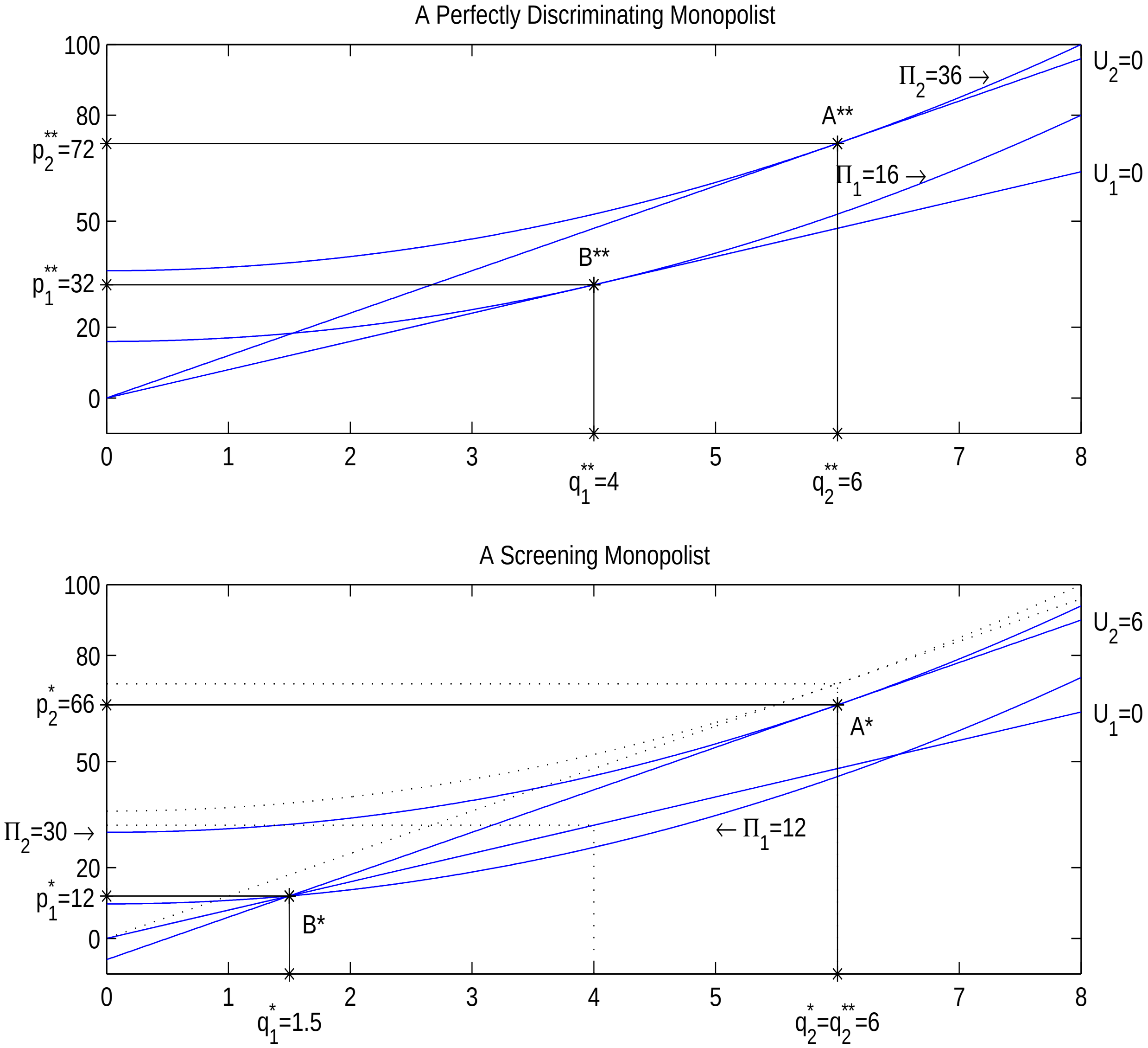
Figure 1 demonstrates graphically the solution for the one-dimensional case with $N = 2$. Look first at the top panel in the figure depicting the solution for a perfectly discriminating monopolist. The straight lines in the figure are indifference curves for each of the two types of consumers; the convex lines are iso-profit lines for the monopolist. The monopolist would ideal offer product qualities $q_1^{**} = 4$ and $q_2^{**} = 6$ at prices $p_1^{**} = 32$ and $p_2^{**} = 66$. At this outcome, total surplus is maximized: qualities are chosen to equate the derivatives of WTP and marginal costs with respect to quality for each product (represented by the tangencies in the top panel of the figure) and the utility to each consumer type is zero. Unfortunately for the monopolist, the high type prefers point B^{**} to his point A^{**} and the equilibrium is unsustainable (utility to consumers is increasing the lower they locate in the figure).

The screening monopolist in the second panel instead selects points A^* and B^*.[17] At this equilibrium, the high type continues to receive the efficient quality, $q^* = q^{**} = 6$, but quality to the low type is degraded from $q_1^{**} = 4$ to $q_1^* = 1.5$. Prices and profits for each type fall. While the low type continues to receive no surplus ($U_1 = 0$), the high type now obtains his "information rent", $U_2 = 6$. How far in general should the monopolist degrade quality to the low-quality good? Well, degrading quality to the low type is costly in that the monopolist must reduce price by more than the decline in his marginal cost. Against that, by degrading quality to the low type, the monopolist may increase the price charged to the high type. In general, the monopolist trades off these factors with the magnitude of the degradation depending on the WTP for quality of each type as well as their weight in the population of consumers (see, e.g., Equation (11) below).

[16] 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.

[17] The indifference curves and isoprofit lines for the discriminating monopolist in the top panel are represented by the dotted lines in the bottom panel.

Figure 1: Quality Degradation with Two Types



3.2 The Rochet-Stole Model

Consider the standard one-dimensional model of Mussa and Rosen (1978) presented above, but modified by modeling the participation constraint as a random variable. As discussed in Rochet and Stole (2002), the primary reason for this generalization is empirical: the MR model imposes very strong properties on consumer demand functions and how they respond to price changes.[18]

Following Rochet and Stole (2002), suppose consumers have preferences over J_n alternatives and an outside alternatives given by

$$\begin{aligned} u_{ijn} &= t_{in}q_{jn} - p_{jn} \qquad \forall j \neq 0 \\ u_{i0n} &= \epsilon_{in} \end{aligned} \tag{9}$$

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_{in} 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 $u_{ijn}(q_{jn}, t_{in}) = t_{in}q_{jn} - p_{jn} - \epsilon_{in}$.

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_{in}. It is in this sense that there is *random participation* but not, however, *random utility*, as that would require additional taste shocks, ϵ_{ijn}, 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.[19]

As in the MR model, assume costs are quadratic, $c(q_{jn}) = \frac{1}{2}q_{jn}^2$ and define the market share function, $M(u,t)$:

$$M_{jn}(u_n, t_n) = \text{Prob}[(\epsilon_{in}, t_{in})|\epsilon_{in} \leq u_{ijn}]$$

with associated hazard rate, $H(u,t) \equiv \frac{M(u,t)}{M_u(u,t)}$.

For the case of discrete types, H nondecreasing in t, and ϵ and t independent, $M_{jn}(u_n, t_n) = G(u_{jn})f_{jn}$, where $G(\epsilon)$ is the cumulative distribution function for ϵ_{ijn}, and profits are

$$\max_{u_{jn}, q_{jn}} E[\pi_n] = \sum_{j=1}^{J_n} f_{jn} G[u_{jn}][S(q_{jn}) - u_{jn}] \tag{10}$$

subject to incentive compatibility $u_{jn} \geq u_{kn} \quad \forall k \neq j$. The only difference in this specification relative to the MR model is the consequence of random participation: $G[u(q_{jn})]$ implies a non-unity share of consumers will purchase at each utility level.

[18] Notably, as in any vertical model, price elasticities are infinite for adjacent products and zero for non-adjacent products. Further, an increase in prices for all products changes the demand only for the lowest-quality product.

[19] 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 in the previous section. The one-dimensional problem with random utility therefore resembles the general, and generally intractable, multidimensional screening problem.

Given this difference, we can compare the MR and RS solutions. The MR Model yields

$$
\begin{aligned}
&u_{1n}^{\mathrm{mr}} = 0 \\
&q_{jn}^{\mathrm{mr}} = \left\{ \begin{array}{ll} t_{J_n} & \text{if } j = J_n \\ t_{jn} - \sum_{j'=j+1}^{J_n} \Delta t_{j'n} \frac{f_{j'n}}{f_{jn}} & \text{else} \end{array} \right\}
\end{aligned} \tag{11}
$$

and the RS Model yields

$$
\begin{aligned}
&u_{1n}^{\mathrm{rs}} \text{ solves } \sum_{j=1}^{J_n} f_{jn}[g(u_{jn})(S_{jn} - u_{jn}) - G(u_{jn})] = 0 \\
&q_{jn}^{\mathrm{rs}} = \left\{ \begin{array}{ll} t_{J_n} & \text{if } j = J_n \\ t_{jn} - \sum_{j'=j+1}^{J_n} \Delta t_{j'n} \frac{f_{j'n}}{f_{jn}} \frac{G_{j'n}}{G_{jn}} \left(1 - \frac{g_{j'n}}{G_{j'n}}(S_{j'n} - u_{j'n})\right) & \text{else} \end{array} \right\}
\end{aligned} \tag{12}
$$

The RS model has two additional terms in the FOC for qualities relative to the MR model: $\frac{G_{j'n}}{G_{jn}}$ increases quality distortion and $(1 - \frac{g_{j'n}}{G_{j'n}}(S_{j'n} - u_{j'n}))$ moderates quality distortion. RS show the solution lies between MR and first-best allocations, implying random participation generally *moderates* quality distortions.

What is the intuition for this result? Well, the MR model permits extraction of *all* of type i's surplus (less his information rents). $[G(u_{jn}) = 1]$, whereas random participation introduces a tradeoff between rent extraction and market share for each type. $[G(u_{jn}) \leq 1]$ The latter assumption is much more plausible for empirical analysis.

3.3 Continuous Types but Discrete Qualities

The theory described to this point has restricted attention to the case where consumers are distributed discretely within each market. This is unrealistic, however: it is far more likely that consumers differ continuously in their preferences for cable service (or any product) quality. This section demonstrates that the theory described above applies also to the case of continuous types, but discrete qualities.

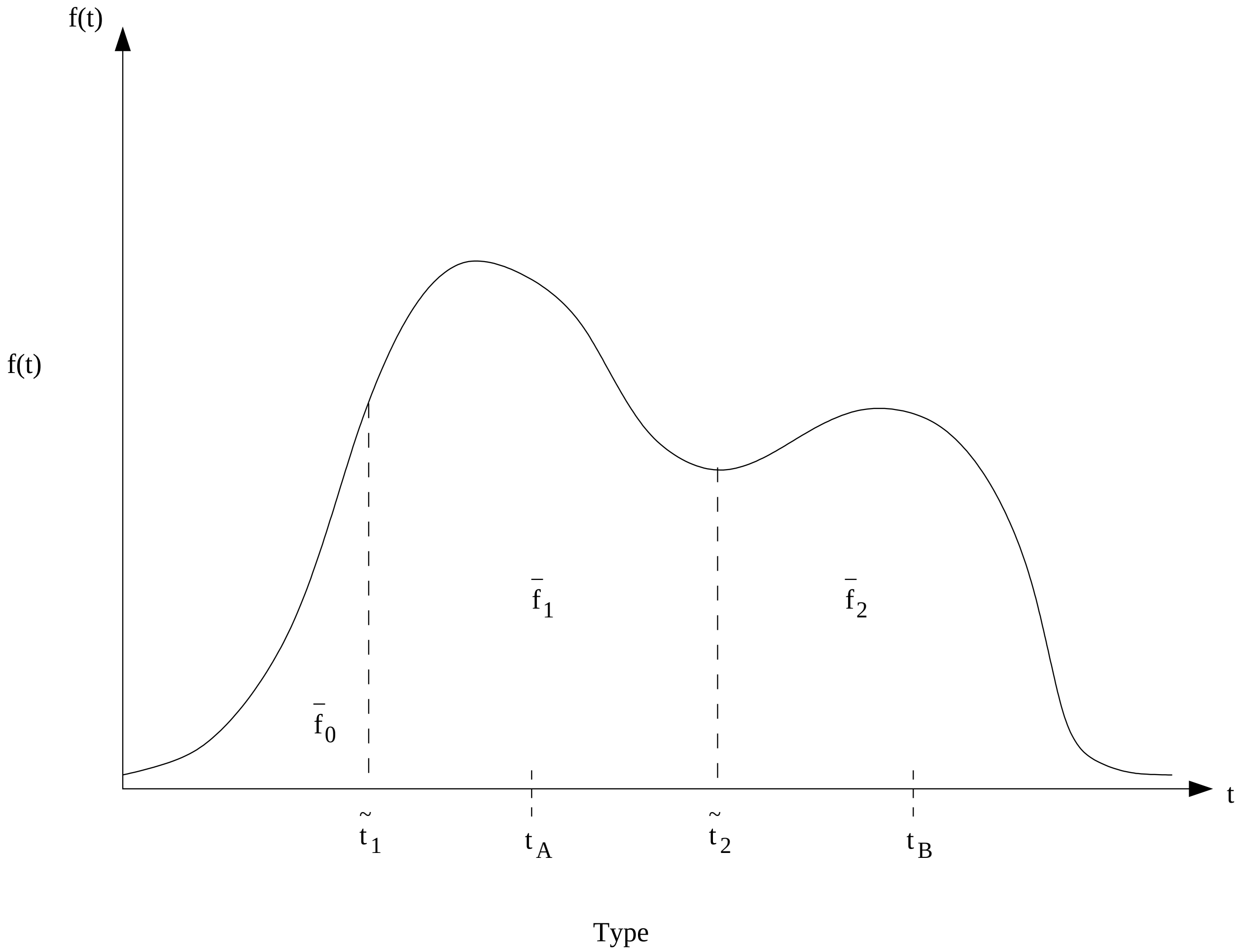
To see this, suppose instead that consumer types are continuously distributed on $[\underline{T}, \bar{T}]$ with pdf, $f(t)$, but that the monopolist has decided to offer just two qualities regardless. She may do so for a number of reasons. The most obvious is that of fixed costs associated with the design, or production of products of different qualities. Or there may be incremental (esp. marketing) costs of offering numerous goods. If these are large, the monopolist will only offer those products that can cover their fixed costs, limiting the number of products in the market (Spence (1980), Dixit and Stiglitz (1977)).

Suppose the firm offered arbitrary qualities, $\bar{q}_1, \bar{q}_2$. Who would buy these goods? All consumers for whom $u(\bar{q}_2, t) \geq u(\bar{q}_1, t)$ and $u(\bar{q}_2, t) \geq 0$ would buy good 2.[20] Because of the structure of the problem – notably the single-crossing condition – only the first of these constraints would bind. Let $\bar{t}_2$ denote the consumer type that is just indifferent between purchasing the two goods, and $\bar{t}_1$ denote the analogous consumer type just indifferent between purchasing good 1 and the outside (i.e. no) good. Then the share of the distribution of consumer types that purchase each good, $\bar{f}_i$, is given by the integral under the distribution between the type cut-points: $\bar{f}_i = \int_{\bar{t}_i}^{\bar{t}_{i+1}} f(t)dt$ (defining $\bar{t}_0 = \underline{T}$ and $\bar{t}_3 = \bar{T}$). Figure 2 presents a graphical representation

[20]For simplicity, we are ignoring random participation in this argument. Everything stated here also applies for that case.

of this framework. In that picture, type t_A lies between the cut-types $\bar{t}_1$ and $\bar{t}_2$, and so consumes the lower bundle. Type t_B lies above the larger cut-type $\bar{t}_2$, and also consumes the higher bundle. For both types t_A and t_B (and for all types other than the cut-types $\bar{t}_1$ and $\bar{t}_2$), both the participation and incentive constraints hold strictly. Given these qualities, $\bar{q}_1, \bar{q}_2$, and associated shares, $\bar{f}_0, \bar{f}_1, \bar{f}_2$, the monopolists profit is again described by equation (7) from the discrete-type case described above.

Figure 2: Continuous Types and Discrete Qualities



There is one important difference, however, in continuous-type cases. With continuous types, the cut-types can be freely varied (by choice of qualities and prices), inducing associated variation in the share of the type distribution purchasing each (or no) good. The monopolists optimal qualities, q_1^*, q_2^*, are then the qualities that yield the greatest profit among all possible quality pairs, $\bar{q}_1, \bar{q}_2$. Let the market share for good j in market n given the cut-types, $\bar{t}_{jn}$, $j = 1, \ldots, J_n$ be given by

$$w_{jn}(\bar{t}_n) = \int_{\bar{t}_j}^{\bar{t}_{j+1}} [\int_{-\infty}^{u_{jn}(t)} g(\epsilon) d\epsilon] f_n(t) dt \tag{13}$$

Then the monopolist maximizes:

$$\max_{\bar{t}_{jn}} \left[\max_{q_{jn}, u_{1n}} E[\pi_n|\bar{t}_n] = \sum_{j=1}^{J_n} w_{jn}(\bar{t}_n)\{S(q_{jn}|\bar{t}_n) - u_{jn}(q_{jn}, u_{1n}|\bar{t}_n)\} \right] \tag{14}$$

subject to incentive compatibility $u_{jn} \geq u_{kn} \quad \forall k \neq j$, where $\bar{t}_n$ is the vector of cut-types for all the products in market n and the dependence of profits on cut-types through $w_{jn}(\bar{t}_n)$, $S(q_{jn}|\bar{t}_n)$, and $u_{jn}(q_{jn}, u_{1n}|\bar{t}_n)$ (from (6)) is made explicit. While this may appear complicated, that $f(t)$ is one-dimensional and cut-types are necessarily increasing simplifies finding the optimal cut-types, $\bar{t}^*$, and associated optimal qualities and prices, $q^*_{jt}(\bar{t}^*)$ and $p^*_{jt}(\bar{t}^*)$. Equation (14) is the objective function of the firms in the econometric estimation presented in the next section.

An important consequence of continuous consumer types is that quality distortion will generally occur for almost all consumers. In particular, only the higher cut-type $\bar{t}_2$ will consume an efficient quality (i.e. $\bar{q}^*_2 = \bar{q}^{**}_2$). All other types $t > \bar{t}_2$ that also purchase the high-quality good (like t_B) will necessarily receive inefficiently low qualities. Similarly, while quality will still be degraded to the lower cut-type (i.e. $\bar{q}^*_1 < \bar{q}^{**}_1$), it will be lower still for other, higher, types (like t_A) that also purchase the low-quality good, i.e. $\bar{t}_1 < t < \bar{t}_2$. This is also illustrated in Figure 1, where the two dashed curves are indifference curves for the types t_A and t_B in Figure 2. Type t_A, who consumes the same bundle as type $\bar{t}_1$, has an efficient bundle which lies to the right of type $\bar{t}_1$'s efficient bundle, implying that the quality distortion to type t_A is higher than that to type $\bar{t}_1$. Similarly, there is a positive distortion to type t_B, even though he consumes the same bundle as type $\bar{t}_2$, to whom there is no distortion. As this illustrates, quality degradation will generally be higher in a continuous-type, discrete-goods setting than the comparable discrete-type, discrete-goods problem.

Note there is one further dimension of firm choice which we have not yet modelled: the number of products offered. As in entry models, this is readily handled by calculating the profit in (14) for each possible $J = \{1, ...J_{\max}\}$, where $J_{\max}$ is the largest number of possible products (here, 3).

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.[21]

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 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.[22]

An important feature of cable system management is their almost complete control over the content and

[21]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.

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

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.[23] Most recently, the 1996 Telecommunications Act removed price controls on Expanded Basic Services, leaving only Basic Service subject to (possible, though extremely weak) regulation. Furthermore, while Direct-Broadcast Satellite service is now a significant competitor to cable service in almost all cable markets, it had only 9.9% of the multi-channel video programming marketplace in 1998, the year of our data (FCC (2000)), and that was concentrated among early adopters in rural areas without access to cable service.[24]

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.[25] Finally, cable systems at this time are arguably monopolists. 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 1998 edition of the Factbook for which complete information was available.[26] From the population, a sample of 5,702 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 20 cable programming networks available in the United States in 1998 are listed in Table 2.

[23]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)).

[24]The watershed date in U.S. cable-satellite competition was November, 1999, when satellite providers were permitted to distribute local broadcast networks into local markets. Since then, every net new subscriber to multi-channel video programming has been a satellite subscriber (Crawford (2005a)).

[25]In a complementary line of analysis, Crawford (2005b) and Crawford (2004) 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 (1999a) 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.

[26]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.

While all systems offer a Basic Service, Table 1 shows that slightly less than 30% of systems offer Expanded Basic Services. Of these, most offer just one Expanded Service. Aggregating over all Basic and Expanded Basic Services, systems typically offer almost 16 cable networks and over 22 other (including broadcast) networks on their highest-quality cable service. Note a convention we will follow throughout the paper is evident from Table 1: to compare cable services across markets with different numbers of services, we generally use a "top-down" approach that compares the highest quality of offered cable services in each market.

5 Empirical Specification

We currently estimate the Mussa-Rosen and Rochet-Stole model under some simplifying assumptions on preferences and costs. We begin with the preference structure common in screening models of endogenous quality choice:

$$\begin{aligned} u_{ijn} &= t_{in} q_{jn} - p_{jn} \\ u_{ij0} &= -\epsilon_{ijn} \end{aligned} \tag{15}$$

where for convenience we've reversed the sign on the random participation error, ϵ_{ijn}. We then assume willingness-to-pay for cable quality has the following form:

$$t_{in} = \tau_{in} + \eta_n + NG_n' \mu_{NG} + \gamma y_n \tag{16}$$

where $\tau_{in} \sim N(\mu, \sigma^2 + NG_n' \sigma_{NG})$, $\eta_n \sim N(0, \sigma_\eta^2)$, y_n is per-capita income in market n, NG_n is the vector of dummy variables indicating the number of goods offered in market n (2 or 3), and σ_{NG} captures variation in the dispersion of preferences in markets offering different numbers of goods. In this specification, there is both within-market heterogeneity in tastes, τ_{in}, as well as both observed and unobserved across-market heterogeneity, y_n and η_n.[27] Furthermore, $\epsilon_{ijn} \sim \text{Exp}(\lambda)$.

We assume the marginal (quantity) cost of providing a cable service of quality q_{jn} is

$$c_{jn}(q_{jn}) = c_0 + (c_1 - \nu_{jn}) q_{jn} + (c_2/\rho) q_{jn}^\rho \tag{17}$$

where ν_{jn} are shocks to marginal costs of quality for product j in market n, with $E(\nu_{jn}) = 0$. Thus, marginal costs are constant across quantity, but vary with the offered quality. For now, we do not introduce cost shifters.

5.1 Identification

Equations (15)-(17) characterizing preferences and costs form the core of the econometric model. Before describing the estimating equations in detail, it is useful to consider the variation in the data that provides identification of these parameters in these equations.

[27]In future versions, we intend to incorporate information about the distribution of income *within* markets. Crawford and Shum (2005) demonstrates this is an informative predictor of offered qualities.

In what follows, we consider the quality of each good j in market n, q_{jn}, to be unobserved to the econometrician.[28] It's place is taken in the empirical model by the value implied by the solution to the monopolist's screening problem given the current estimate of the preference and cost parameters, i.e. $q_{jn} = q_{jn}(\theta)$ where $\theta = (\mu, \sigma, \sigma_\eta, \gamma, \mu_{NG}, \sigma_{NG}, c_0, c_1, c_2, \rho, \lambda)$. We show in the next subsection that the market shares and prices that come out of the model are complicated nonlinear functions of these parameters.

What, then, is driving identification? The main source of variation in our dataset is across markets n. In this version of the paper, we have few covariates and identification exploits the fact that markets with the same number of goods NG_n and similar incomes y_n should exhibit similar prices and market shares. If, for example, prices are higher in one market, it must be the case that there are higher unobserved tastes for quality, η_n, a fact that will also induce higher chosen quality, q_{jn}, by the monopolist (at least for the high-quality good). Parameters in the cost function are identified by what best fits the sample data.[29]

5.2 Estimating Equations

The estimation compares moments of the observed data with those generated by the model. As we consider quality to be unobserved to the econometrician, we rely only on the model predictions for market shares, w_{jn}, and prices, p_{jn}, for products $j = 1, \ldots, J_n$ in market n.[30]

Recall firms optimally select both the cut-types in each market as well as prices and qualities given these cut-types. Cut-type $\bar{f}_{jn}$ purchases product j as long as it's utility is greater than that from the outside good, i.e. $\bar{t}_{jn} q_{jn} - p_{jn} \geq \epsilon_{ijn}$. As earlier, market shares are given by

$$w_{jn} = \int_{\bar{t}_j}^{\bar{t}_{j+1}} [\int_{-\infty}^{u_{jn}(t)} g(\epsilon) d\epsilon] f_n(t) dt \tag{18}$$

where $u_{jn}(\bar{t}_{jn}) = \bar{t}_{jn} q_{jn} - p_{jn}$. In the estimation, we calculate (13) using simulation with 100,000 draws.

We assume there is measurement error in market shares such that

$$w_{jn}^{\text{obs}} = w_{jn}(X, \theta) + \tau_{jn} \tag{19}$$

where w_{jn}^{obs} are the observed market shares (cf. Table 1), $w_{jn}(X, \theta)$ are the market shares predicted by the model as a function of exogenous variables, X, and parameters, θ. The exogenous variables in this specification are a constant, average income, and dummy variables for each product/number-of-product combination (i.e. good 1 in 1-good markets, goods 1 and 2 in two-good markets, etc.). The parameters to be estimated are $\theta = (\mu, \sigma, \sigma_\eta, \gamma, \mu_{NG}, \sigma_{NG}, c_0, c_1, c_2, \rho\lambda)$.

As described in the discussion following Equation (8), prices given optimal qualities and utility to the lowest type (for the optimal cut-types, $\bar{t}^*$) are given by

[28] We will later relate it to the networks offered on service j in market n by a regression of our estimates of q_{jn} on $X'_{jn}\beta + \xi_{jn}$.

[29] Going forward, identification will be driven by variation in the composition of Basic cable services across markets. Because the networks offered on cable service are common across markets, service quality must therefore vary in predictable ways across markets (i.e. depending on the networks offered on each service in each market). This will help separately identify preferences for quality from the quality of offered services. Similarly, we can exploit commonality in the structure of costs for cable systems owned by a common firm to help identify the cost parameters.

[30] We can also (but don't yet) predict the number of products, J_n.

$$p_{jn} = \bar{t}^*_{jn} q^*_{jn}(\bar{t}^*) - u^*_{jn} \qquad \text{where}$$
$$u^*_{jn} = u^*_{1n}(\bar{t}^*) + \sum_{j'=1}^{j-1} \Delta \bar{t}^*_{j'n} q_{j'n}(\bar{t}^*) \tag{20}$$

where $\Delta \bar{t}^*_{jn} \equiv \bar{t}^*_{j+1,n} - \bar{t}^*_{jn}$. Since q_{jn} is linear in marginal quality cost shocks, ν_{jn}, so too is p_{jn}.

Formally, let

$$p^{\text{obs}}_{jn} = p_{jn}(X, \theta) + \tilde{\nu}_{jn} \tag{21}$$

where p^{obs}_{jn} are the observed prices and $p_{jn}(X, \theta)$ are the prices predicted by the model.

Let $\omega = [\tau' \ \tilde{\nu}']'$ be the stacked vector of econometric errors and let $X = [D_{jn} \quad D_{jn} Y_n]$ be the matrix of instruments, where D_{jn} = dummy variables for each combination of product/number-of-products pairings (e.g. good 1 in 1-good markets, goods 1 and 2 in 2-good markets, etc.) and Y_n = per-capita income in market n.

Formally, we minimize the objective function

$$Q = \omega(\theta)' X W X' \omega(\theta) \tag{22}$$

where W is the weighting matrix. In the results presented here, we use an estimate of the optimal weighting matrix $W = [V(X'\omega(\theta))]^{-1}$, where we obtained an initial consistent estimate of θ using weighting matrix $W = (X'X)^{-1}$.

5.3 Estimation Specifics

We employ a two-step estimation procedure. We first obtain estimates of the fundamental model parameters, θ. We then use these parameters to infer the quality offered on each service in each market and relate those to the television networks carried on those services. The first step is by far the more difficult.

The first step is itself a three-level nested estimation algorithm. In the *inner loop*, we solve for the optimal qualities (and lowest utility), (q_j, u_1), as a function of the current estimate of cut-types, $\bar{t}_{jn}$, in market n. Predictions for the observed prices and market shares follow from these qualities/utility. This is done numerically either by solving the nonlinear system of FOC defined by equation (12) or by a non-derivative routine that maximizes (10).

In the *middle loop*, we solve for the optimal cut-types, $\bar{t}_{jn}$ in market n given the current estimate of the model parameters, θ. Together, the inner and middle loops are described by equation (14). In the *outer loop*, we search for values of model parameters, θ, that minimize our objective function, Q. At each level, we use non-derivative (simplex) methods with informative starting values.

An important computational issue arises in practice: our three-level estimation algorithm is slow. Very slow: a single evaluation of Q for our 5,717 markets using Matlab on a 2.00 GHz PC with 1 GB of RAM takes roughly 2 hours. The structure of our problem provides an attractive solution, however. While the distribution of types is assumed to vary across markets (with NG_n, Y_n, and η_n), in all cases it is a normal distribution with mean μ_n and standard deviation σ_n. These preference parameters – μ_n, σ_n, and λ - along with the cost parameters – c_0, c_1, c_2, and ρ - are all that are required to solve for the optimal prices and qualities, associated market shares, and all other outcome variables of interest (e.g. consumer welfare and profit measures). As a result, we establish a grid over the range of reasonable values of these parameters, solve the model at those grid points, and interpolate values for all the outcome variables between those points. For the results presented in Table 3, we used a range of [2,7.5] for μ_n, [0.3,.7] for σ_n, [0.11,0.91] for λ, [0.3,0.7] for c_0, [0.2,0.6] for c_1, [0.5,1.0] for c_2, and [2,2.6] for ρ with 3 grid points in each dimension.[31] For these values, solving for the outcome variables across the whole of the grid for each number of goods offered in each market (1, 2, and 3) took 3 hours, but reduced the time required to evaluate Q to about 0.1 seconds!

At the converged parameter estimate, $\hat{\theta}$, we re-run the middle and inner loops to calculate the profit-maximizing cut-types and fitted values for market shares, prices, and (importantly) qualities, q^*_{jn}. The second step in our estimation procedure then explains how this quality varies with the components of the service bundles across markets:

$$q^*_{jn} = z'_{jn}\beta + \xi_{jn}, \ \forall i, n \tag{23}$$

where z_{jn} = characteristics of the i-th bundle in market n.

Equation (23) 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 $E[q^*|Z_{in}] = \beta'_i Z_{in}$. In this case, the residuals ϵ_{in} represent pure prediction error which by construction satisfies the orthogonality restriction $E[\epsilon|Z_{in}] = 0$. With this interpretation, the coefficients β cannot be interpreted as the causal effects of changes in Z_{in} 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 (23) as a structural equation which posits a deterministic relation between (Z_{in}, ϵ_{in}) and perceived quality q^*_{in}. Here, (Z_{in}, ϵ_{in}) are (resp.) the observed and unobserved characteristics of the i-th bundle in market n. In this case, a consistent estimate of β can be interpreted as the causal effect of changes in Z_{in} on perceived quality q^*. However, in this case, we obtain a consistent estimate of the structural parameter β via regressing q^* on Z only when $E[\epsilon_{in}|Z_{in}] = 0$ (i.e., Z is "exogenous"). When this orthogonality restriction does not hold, we must find appropriate instruments W_{in} so that $E[\epsilon_{in}|W_{in}] = 0$. Candidate instruments should, roughly speaking, be correlated with the observed characteristics Z_{in} but uncorrelated with the unobserved characteristics (or "unobserved quality"). If we interpret ϵ_{in} as market n's idiosyncratic valuations for the components in bundle i, then appropriate instruments could perhaps be the $Z_{ic'}$ in markets c' which are either close to market n, or served by the same cable provider which serves market n (cf. Crawford (2005b)).

[31] We interpolate using the Matlab Interpn function which necessarily constrains us to linear interpolation. Fortunately, almost all the outcome variables are monotonic in each dimension - the exception is for σ for some values of μ - suggesting interpolation will be an effective strategy. For some simple experiments using 10 grid points and linear interpolation, there was a maximal difference of about 0.2% between the interpolated and true outcome variables across the whole of the grid (and a much lower average difference). Approximation errors are much lower with shape-preserving approaches to interpolation, something we will implement in future revisions.

Endogenous Quality versus BLP There are some interesting similarities between our estimation algorithm and the estimation algorithm develop in Berry (1994) and Berry, Levinsohn, and Pakes (1995) (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, there are some important differences for what we propose and the BLP algorithm. Most important is that we incorporate the choice of quality by firms. As demonstrated in the monte carlo presented in Appendix A, firms will tend to offer higher qualities in markets with greater tastes for quality. Ignoring this feature will bias estimated tastes for both quality and price (money), although the sign of the bias will depend on the correlation between offered qualities and the error, *conditional on price*. While the unconditional correlation between tastes for quality and offered qualities is likely positive, prices can also depend on unobserved tastes in ways that make the conditional correlation difficult to predict.

Another important difference is that our algorithm incorporates the restrictions implied by optimal firm behavior, while the BLP algorithm does not have to.[32] While this may be perceived to be a weakness, we view it as a potential strength of the approach. One of the difficulties in the BLP approach is the difficulty identifying features of the distribution of tastes within markets. Screening models, however, have very strong predictions about how offered prices and qualities (and thus market shares) vary with changes in these distributions across markets. As such, variation in features of the distribution of household characteristics estimated to influence tastes (e.g. mean, variance, and skewness of income and household size) can provide significant explanatory power in ways that simple means cannot. We present reduced-form evidence of the importance of the features of the distribution of income, age and household size on offered cable qualities in Crawford and Shum (2005) and will incorporate this information in our estimation algorithm in subsequent revisions.

6 Results

Table 3 presents parameter estimates from the endogenous quality model. Reported are point estimates and heteroskedasticity-consistent asymptotic standard errors. All the estimates are statistically significant at conventional levels and appear reasonable: mean WTP for quality is 4.77/4.90/5.62 in 1/2/3-good markets, respectively, with corresponding standard deviations 0.46/0.44/0.33.[33] While the impact of income (γ) is not significant, unobserved variation in tastes for cable service quality (σ_η) is important. Preferences for random participation are quite diffuse, suggesting significant substitution for the outside good even among those with high preferences for quality.

[32] In the original paper, Berry, Levinsohn, and Pakes (1995) do incorporate the restrictions of Bertrand-Nash pricing in estimation. Others do not, however (Nevo (2001)). Including the pricing equation can increase the efficiency of estimation at the risk of inconsistency for all the parameters if the assumption of Bertrand-Nash pricing is incorrect.

[33] The increase in mean and reduction in dispersion in preferences for bundles is consistent with the impact of increasing bundle size (cf. Table 1) on preferences for bundles (e.g. Crawford (2005b)).

Given these estimates, we have an estimate of the distribution of preferences in each cable market, n. From these, we next calculate the optimal cut-types (measuring willingness-to-pay for quality for the household just indifferent between purchasing that and the lower quality), implied qualities, and associated market shares and prices. We can also calculate the amount of degradation of offered qualities relative to that provided by a competitive market offering the same number of goods.[34] Table 4 report our estimates of these values as well as how the prices and shares compare with those in the sample.

Looking first at the fit in the top panel of the table, we see that the fit is adequate. There is no discernable pattern to either market share or price errors. The assumption of normally-distributed tastes is strong in our context; we will relax it in subsequent revisions.[35]

With respect to quality degradation, we find that there is significant degradation, particularly for markets offering more than one good. We find that offered qualities are an estimated 5% and 24% less in 3-good markets and 23% less in 2-good markets for households just indifferent between purchasing each good and the good of the next lowest quality.[36] Quality to the highest-quality good is estimated to be higher than that is efficient for the marginal consumer.

What impact does this quality degradation have on consumer and social welfare? To address this question, we first calculate the "quality markup" for the marginal consumer. This is given by the percentage difference in the derivative of willingness-to-pay with respect to quality ($\partial u/\partial q = \partial(tq)/\partial q = t$) and the derivative of marginal cost with respect to quality ($\partial c(q)/\partial q = c_1 + c_2 q^{\rho-1}$), evaluated at the marginal consumers, $\bar{t}_j$. Consistent with the quality degradation figures above, quality markups are -12/5/24% in 3-good markets, -1/23% in 2-good markets, and -5% in 1-good markets.[37] By comparison, price-cost markups are 48/50/58%, 46/37%, and 41% in 3/2/1-good markets. At least for the marginal consumer, the welfare consequences of quality reductions under monopoly are between one-third and one-half that of quantity reductions under monopoly.

Given the structure of preferences and costs, we can also simulate the profit and welfare consequences of alternative portfolios of offered qualities. We consider two counterfactuals: one with qualities fixed at that set by the multiproduct monopolist but with prices equal to marginal costs at that quality and another with qualities set at the efficient level but allowing monopoly pricing. While not realistic counterfactuals for policy purposes, these are useful in describing the relative importance of monopoly pricing versus monopoly quality choice is driving welfare outcomes. Table 5 presents the results of these counterfactuals. As expected, qualities that maximize total surplus are generally higher, but allowing monopoly pricing increases prices to consumers. Consumer surplus jumps significantly under either counterfactual, although generally more from efficient pricing of monopoly qualities. Total surplus increases by 3.3/55.7/53.7% in (1/2/3)-good markets from efficient pricing given monopoly qualities and by -2.4/62.1/15.1% from monopoly pricing at efficient qualities.[38]

[34] $q_i^* = 2\bar{t}_i$ for the cut-types in the specification presented here.

[35] Allowing a more flexible distribution of preferences in each market appears feasible but requires expanding the "state space" of the endogenous quality model to include a flexible specification of $\bar{t}$ and $\bar{f}$.

[36] This is a lower bound on the average degradation for all households. [To Do: Calculate the average degradation.]

[37] Negative numbers here mean that the change in marginal cost w.r.t. quality actually exceeds the change in WTP w.r.t. quality for the marginal consumer.

[38] The discrepancy between the markup and welfare figures for these preliminary results appear to be driven by large welfare gains to consumers with extreme tastes for quality, a common problem arising when using distributions of preferences with unbounded support (e.g. Petrin (2003)). We will explore this issue further in subsequent revisions.

Finally, Table 6 reports the results of the 2nd-stage quality regressions described earlier. Reported are the parameter estimates from an OLS of implied qualities on the top-15 cable networks reported in Table 2. On the assumption this is a structural equation, also reported are the implied mean willingness-to-pay for each network (using the mean of WTP for quality in 3-good markets, 4.11). 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.

Note the implied relationship between networks and quality are generally reasonable in sign and magnitude. Most are positive and significant with a range of mean WTP (among significant coefficients) between -\$0.40 (for CSPAN) and \$3.13 (for ESPN).[39] Additional networks outside the top-15 are valued at \$0.03 each. Second, among networks in common, the results are generally more reasonable for those from the endogenous quality model than those we found earlier in Crawford (2000). 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. More work needs to be done regarding specification choice for our estimation, however, before taking these results as conclusive.

7 Conclusions and Extensions

The purpose of this paper is to measure the econometric and economic consequences of endogenous quality choice by a multiproduct monopolist. It is based on a model of nonlinear pricing with random participation recently developed by Rochet and Stole (2002). Preliminary results appear reasonable and suggest the welfare consequences from monopoly quality choice may be on the order of half as large as those from monopoly pricing.

Several immediate extensions of the existing analysis are suggested. First, the empirical specification can be extended to allow for a more flexible structure of consumer preferences. So too can we model the choice of the number of products offered by firms. Since more products are necessarily more profitable, that they are not offered suggests fixed costs from offering multiple cable services, something we will be able to estimate from the data. 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.

More broadly, one goal of this paper is to introduce the empirical literature to the value of screening models for modeling endogenous product choices. Two areas of current theoretical research look promising for using these techniques in applications outside monopoly cable markets. The first is to incorporate multiple dimensions of consumer preferences. Consumers typically care about multiple product attributes, especially horizontal (e.g. brand) attributes. While this requires models of multidimensional screening, the same simplifications that arose in the single-dimensional setting from the discreteness of firms' offered products may make these models empirically feasible. The second, complementary, extension is to consider competition

[39] Interpreting parameters with negative coefficients can be a challenge. One possibility is simply that they are not measuring the true causal effect of the network on cable service quality. Another is that preferences for cable quality depend on preferences for the underlying networks encompassing that quality. In this more general model, negative mean values likely proxy for a mass of consumers with zero WTP; this can be consistent with profit-maximization if there are at least some consumers with positive tastes for the network. In related work, Crawford (2004) seeks to estimate the distribution of tastes for networks from demand for bundles.

with endogenous quality choice. While also challenging, models of competition under nonlinear pricing or endogenous quality choice exist (Stole (1995), Rochet and Stole (2002), Miravete and Roller (2003)) and are more generally applicable than the monopoly model considered here. Both of these are lucrative areas of further research.

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.	0.29	1.00	1.00	0.00
One Exp. Basic Svc.	0.26	0.00	1.00	0.00
Two Exp. Basic Svcs.	0.04	1.00	0.00	0.00
Market Shares				
w_3	0.61	0.47	0.60	0.62
w_2	0.03	0.13	0.09	—
w_1	0.00	0.05	—	—
Prices				
p_3	21.10	29.06	23.06	19.99
p_2	4.08	22.65	12.75	—
p_1	0.64	18.26	—	—
Programming				
Top-20 Cable Networks				
On Service 3	11.86	16.40	15.62	10.27
On Service 2	2.28	13.18	7.05	—
On Service 1	0.30	8.57	—	—
Other Than Top-20 Cable Networks				
On Service 3	4.09	8.43	5.97	3.19
On Service 2	0.87	5.62	2.61	0.00
On Service 1	0.15	4.36	0.00	0.00
Homes Passed (millions)	6.50	8.63	14.22	3.58
Channel Capacity	38.61	43.83	44.96	36.04
Per-Capity Income	16.58	17.33	17.76	16.11
Franchise Fee	1.44	3.09	2.05	1.13
Observations	5,702	201	1,467	4,034

Notes: Data on cable systems, including service, market share, price, and programming data from Warren (1998). Data on demographic information from Census (1994).

Table 2: Top-20 Cable Programming Networks

Rank	Network	% U.S. Homes	Programming Format
1	TBS Superstation	74.9	General Interest
2	ESPN	74.3	Sports
3	Discovery Channel	74.2	Nature
4	CNN (Cable News Network)	74.1	News
5	C-SPAN	74.0	Public Affairs
6	USA Network	73.8	General Interest
7	TNT	73.7	General Interest
8	Nick	72.5	Kids
9	Family Channel	72.2	General Interest/Kids
10	TNN	72.0	General Interest/Country
11	A&E	71.5	General Interest
12	Lifetime Television	70.8	Women's
13	The Weather Channel	70.2	Weather
14	MTV: Music Television	69.4	Music
15	AMC (American Movie Classics)	68.5	Movies
16	Headline News	68.4	News
17	QVC	65.7	Home Shopping
18	CNBC	64.7	News
19	The Learning Channel (TLC)	63.7	Science
20	VH1	61.7	Music

Notes: Data on percent coverage for 1997 from Kagan World Media (1998). Data on programming formats from individual network promotional material (available from http://www.ncta.com), NCTA (1998), or industry sources.

Table 3: Estimates

Preference Params		Cost Params	
	Estimate **Std. Err.**		**Estimate** **Std. Err.**
μ	**4.77**	c_0	0.32
	(0.96)		(0.70)
σ	**0.46**	c_1	**0.20**
	(0.17)		(0.04)
σ_η	**0.72**	c_2	**0.99**
	(0.21)		(0.21)
γ	0.002	ρ	**2.21**
	(0.002)		(0.17)
μ_2	0.13		
	(0.11)		
σ_2	-0.02		
	(0.17)		
μ_3	**0.85**		
	(0.22)		
σ_3	-0.13		
	(0.19)		
λ	**0.87**		
	(0.07)		
Obs.	7,571		

Notes: Reported are results from GMM estimation of the Rochet-Stole endogenous quality model. Number of observations is 4,034 for Basic, 1,467 for Expanded I, and 201 for Expanded II. Heteroscedasticity-consistent standard errors are reported in parentheses. μ_j and σ_j for $j = \{2, 3\}$ are increments to the mean and standard deviation of household WTP for quality in 2- and 3-good markets, respectively.

Table 4: Fit, Quality Degradation, and Welfare

	3-Good Markets			2-Good Markets			1-Good Markets		
Fit	Sample	Pred	Diff	Sample	Pred	Diff	Sample	Pred	Diff
w_3	0.47	0.51	-0.04	0.60	0.53	0.07	0.62	0.63	-0.01
w_2	0.13	0.18	-0.05	0.09	0.12	-0.03	—	—	—
w_1	0.05	0.05	0.00	—	—	—	—	—	—
p_3	29.06	26.97	2.08	23.06	21.89	1.17	19.99	19.82	0.17
p_2	22.65	22.62	0.02	12.75	15.98	-3.23	—	—	—
p_1	18.26	17.62	0.64	—	—	—	—	—	—
Quality Degradation	Offered Quality	Efficient Quality	% Deg	Offered Quality	Efficient Quality	% Deg	Offered Quality	Efficient Quality	% Deg
q_3	4.41	3.97	-0.12	3.86	3.83	-0.01	3.61	3.45	-0.05
q_2	3.60	3.79	0.05	2.64	3.41	0.23	—	—	—
q_1	2.71	3.55	0.24	—	—	—	—	—	—
	CS	Profit	TS	CS	Profit	TS	CS	Profit	TS
Welfare	6.15	11.36	17.52	4.32	8.98	13.29	3.06	8.37	11.43
Observations		201			1,467			4,034	

Notes: Reported are measures of fit, estimated quality, quality degradation, and welfare measures from the baseline (Rochet-Stole) specification. Reported for fit are the sample and predicted market shares and prices as well as their difference. "Offered quality" is the average across markets estimated from the endogenous quality model given the parameter estimates in Table 3 and market-specific variables. "Efficient quality" is that which would equate WTP for quality with its marginal cost for the household just indifferent between purchasing each offered good and the lower-quality good. Percentage degradation is relative to the efficient quality. CS = Consumers Surplus, TS = Total Surplus. Welfare measures are estimated 1998 dollars per household per month.

Table 5: Estimated and Counterfactual Outcomes

	3-Good Markets			2-Good Markets			1-Good Markets		
	Mon Q Mon P	Mon Q Eff P	Eff Q Mon P	Mon Q Mon P	Mon Q Eff P	Eff Q Mon P	Mon Q Mon P	Mon Q Eff P	Eff Q Mon P
Shares									
w_3	0.51	0.85	0.35	0.53	0.81	0.04	0.63	0.85	0.62
w_2	0.18	0.05	0.16	0.12	0.05	0.56	—	—	—
w_1	0.05	0.00	0.21	—	—	—	—	—	—
Prices									
p_3	26.97	14.76	33.73	21.89	11.93	32.75	19.82	10.65	22.59
p_2	22.62	10.98	30.83	15.98	7.07	26.12	—	—	—
p_1	17.62	7.24	27.46	—	—	—	—	—	—
Quality									
q_3	4.39	4.39	5.57	3.86	3.86	5.54	3.61	3.61	4.10
q_2	3.58	3.58	5.06	2.64	2.64	4.56	—	—	—
q_1	2.70	2.70	4.47	—	—	—	—	—	—
Welfare									
CS	6.15	26.93	9.15	4.32	20.71	12.85	2.98	11.96	2.87
Profit	11.36	0.00	10.88	8.98	0.00	8.52	8.60	0.00	8.41
TS	17.52	26.93	20.03	13.29	20.71	21.37	11.57	11.96	11.29
Relative to Baseline									
CS	—	3.37	0.50	—	3.77	2.00	—	3.02	-0.04
Profit	—	-1.00	-0.04	—	-1.00	-0.05	—	-1.00	-0.02
TS	—	0.54	0.15	—	0.56	0.62	—	0.03	-0.02

Table 6: Parameter Estimates

Cable Programming Parameters

Variable	Estimate (StdErr)	Implied Mean WTP	Crawford (2000) Mean WTP
WTBS	**0.17** (0.03)	0.94	0.93
ESPN	**0.56** (0.03)	3.13	5.50
Discovery	-0.01 (0.02)		-0.39
CNN	0.02 (0.03)		-0.39
CSPAN	**-0.07** (0.02)	-0.40	—
USA	**0.19** (0.02)	1.08	0.91
TNT	**0.09** (0.02)	0.50	-0.38
Nickelodeon	-0.04 (0.02)		—
Fox Family	**-0.04** (0.02)	-0.24	-1.22
TNN	**0.09** (0.02)	0.52	-0.53
A&E	**-0.06** (0.02)		—
Lifetime	-0.01 (0.02)		—
Weather	-0.01 (0.02)		—
MTV	0.02 (0.02)		0.19
AMC	**0.09** (0.02)	0.50	—
Other Nets.	**0.01** (0.00)	0.03	0.10

Notes: Reported are coefficient estimates from regressions of recovered quality levels on broadcast and cable programming variables. Results are for the top 15 cable networks listed in Table 2. Pooled across all markets, and across all products within a market. Standard errors in parentheses. Second column (for statistically significant estimates) from authors' calculations; estimated WTP is product of regression coefficient in first column with the estimated mean WTP for quality in 3-good markets (5.62). Also reported are similar calculations from Crawford (2000).

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