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**Testing for Monopoly Power when
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ABSTRACT

Testing for Monopoly Power when Products are Differentiated in Quality

by Frank Verboven^{*}

This paper proposes a reduced form approach to identify the presence of monopoly power in oligopolies characterized by vertical product differentiation. In a fairly general model I derive an explicit solution for the reduced form pricing equations under the hypothesis that firms behave collusively. The central comparative statics result states that a product's price depends only on its own quality and not on the quality of its competitors. I propose econometric tests implied by this result, requiring only the data used in popular hedonic studies (prices and physical characteristics). The tests are applied to the market for spreadsheets in the U.S. (1986-1991) and to the market for "engine variants" in the 1990 French car market. The empirical results are encouraging, because they are consistent with some *a priori* evidence on these industries. Nevertheless, to widen to the scope for economic applications, some further generalizations of the model are called for.

ZUSAMMENFASSUNG

Überprüfung der Monopolmacht bei qualitativ differenzierten Produkten

In dem Beitrag wird ein reduzierter Gleichungsansatz vorgeschlagen, um Monopolmacht auf Oligopolmärkten mit vertikaler Produktdifferenzierung festzustellen. In einem ziemlich allgemeinen Modell wird die explizite Lösung für die reduzierte Form der Preisgleichung unter der Hypothese abgeleitet, daß die Unternehmen sich kollusiv verhalten. Das zentrale komparativ-statische Ergebnis besagt, daß der Produktpreis nur von der eigenen Qualität und nicht der Qualität der Konkurrenten abhängt. Es wird ein ökonometrischer Test vorgeschlagen, der dieses Ergebnis berücksichtigt und sich nur auf Daten stützt, die in üblichen hedonistischen Untersuchungen mit Preisen und Produktmerkmalen verwendet werden. Der Test wird auf den Markt für Tabellenkalkulations-Programme in den USA (1986-1991) angewendet und auf den Markt für "Motorvarianten" als Teilmarkt des französischen Automobilmarkts (1990). Die empirischen Ergebnisse sind vielversprechend, weil sie mit *a priori* Annahmen über diese Industriezweige konsistent sind. Dennoch erscheint ein gewisse Verallgemeinerung des Modells angebracht zu sein, um sein ökonomisches Anwendungsspektrum zu erweitern.

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1. Introduction

During the past two decades there has been a revived interest in the empirical identification of market power in oligopolistic industries. Price--cost margins from accounting data are no longer taken to be reliable measures of market power. Instead, market power is inferred indirectly from observed firm behavior (prices, sales) and the predictions of a suitable oligopoly model. Most of this research has focused on the estimation of structural form models.¹ A structural form model of an oligopoly typically consists of both a demand equation and a "supply" equation, determining the oligopolistic equilibrium. Estimating the structural parameters of this system is usually regarded as very appealing because it allows for a clear economic interpretation of the empirical results (e.g. the estimation of price-cost margins), and because it provides a basis for quantitative policy analysis through model simulations.

The structural form approach, however, also has its drawbacks. First and most importantly, it requires specific assumptions about the functional forms. A hypothesis test for the presence of market power is then always conditional on a "correct" specification of the demand and supply functions. Second, the structural form approach requires data on *all* endogenous variables in the model, which is not always possible. Finally, the econometric procedures required to estimate even simple structural form models are frequently computationally burdensome. To avoid these problems, a reduced form approach may often be a valid alternative to identify market power. This approach searches for comparative statics predictions that necessarily hold in the presence of monopoly power and not under more competitive behavior, such as Bertrand-Nash behavior. These comparative statics predictions can then be tested by estimating a reduced form regression, writing the relevant endogenous variables (such as prices, quantities or revenues) as a function of the exogenous variables solely.

In this paper I propose a reduced form approach to identify the presence of monopoly power in oligopolies characterized by vertical product differentiation, i.e. differentiation in quality. In a fairly general model of one-dimensional vertical product differentiation I

¹ Geroski (1988) and Bresnahan (1989) provide surveys of the literature.

derive an explicit solution for the reduced form pricing equations under the hypothesis that firms collude by maximizing their joint-profits. The central comparative statics result states that a product's price depends only on its own quality and not on the quality of its competitors. In the absence of collusion this comparative statics result is not likely to hold. I propose econometric tests implied by the comparative statics result. The tests require only the data used in popular "hedonic" studies, i.e. data on the prices and physical characteristics of the products.

To illustrate, I have applied the tests to two different industries: the market for spreadsheets in the U.S.(1986-1991) and the market for "engine variants" in the 1990 French car market. The empirical results are encouraging because they are consistent with some *a priori* evidence on the presence of monopoly power in these industries. This indicates the usefulness of the tests as a first approach in detecting the presence of collusion when there is vertical product differentiation. Nevertheless, to widen the scope for economic applications, some further generalizations of the model are called for.

Bresnahan (1987) has used a structural model of vertical product differentiation to test for the presence of collusion in the U.S. car market during the mid-fifties. He finds evidence for collusion in 1954 and 1956, interrupted by Bertrand-Nash behavior in 1955. Bresnahan's model is a special case of the model presented in this paper, it requires more data, and, as discussed by Berry (1994), it is computationally demanding. It would be interesting to investigate whether the simple tests developed in the present paper would yield similar conclusions as those obtained by Bresnahan.

Almost all of our recent knowledge on market power uses identification arguments based on comparative statics in *either* cost or demand. There have not yet been formal identification arguments based on comparative statics in variables that influence *both* cost and demand, such as quality. Furthermore, most of our knowledge on market power comes from the estimation of structural form models of oligopoly. Interest in the testable predictions from reduced form oligopoly models has been scarce. The most notable exception is by Panzar and Rosse (1987). They discover a testable comparative statics prediction about the effect of factor prices -- or more generally all exogenous variables influencing cost but not demand -- on revenues. This prediction necessarily holds in the

presence of monopoly power, and not under more competitive behavior.² Panzar and Rosse emphasize the generality of their result and the applicability even when data on prices and quantities are not separately available. In principle, their test can be applied to all industries, including industries characterized by product differentiation. In practice, however, industries with product differentiation often fail to meet the data requirements in order to implement the test. Data on revenues and on factor prices (or other exogenous variables affecting cost but not demand) are generally not available at the product level. In industries with product differentiation the most accessible data come from retail catalogues, providing product-level information on prices and physical characteristics. Physical characteristics influence *both* cost and demand, so that Panzar and Rosse's test cannot be applied. In contrast, the tests developed in this paper, or some variant thereof, are immediately applicable, if the physical characteristics provide a reasonable measure of quality.

The model is presented in section 2. Sections 3 and 4 derive the reduced form pricing equation and the central comparative statics result. Section 5 proposes the empirical tests, which are applied in section 6. Section 7 provides suggested extensions.

2. The model

Consider the following model of vertical product differentiation, related to the model introduced by Mussa and Rosen (1978).³ There are N consumers, all endowed with income I , and $n + 1$ goods, $i = 0 \dots n$, where good 0 is an outside good. A good i has a quality v_i and is sold at a price p_i . Rank the qualities in increasing order as $v_0 < v_1 < \dots < v_n$. The conditional indirect utility of a consumer of type \mathbf{q} buying product i is given by

$$u_i(\mathbf{q}) = I + v_i \mathbf{q} - p_i, \quad i = 1 \dots n$$

² More precisely, they show that the sum of the effect of the factor price elasticities on a monopolist's reduced form revenue equation is always nonpositive. This property may not hold in the absence of monopoly power.

³ Mussa and Rosen look at a continuum of products. They make use of quite different techniques, in a mechanism design framework. Nevertheless, some of the results here show some interesting similarities, as the interested reader may verify.

where $\mathbf{q}\hat{\mathbf{I}} [\mathbf{q}, \bar{\mathbf{q}}]$ is a taste parameter representing consumer \mathbf{q} 's marginal willingness to pay for quality, with $0 \leq \mathbf{q} < \bar{\mathbf{q}}$. The cumulative distribution of the taste parameter \mathbf{q} in the population of consumers is denoted by $F(x) = P(\mathbf{q} \leq x)$, with corresponding density $f(x)$. Let $F(x)$ be continuous, differentiable and nondecreasing, with $F(\mathbf{q}) = 0$ and $F(\bar{\mathbf{q}}) = 1$.

A consumer of type \mathbf{q} is indifferent between purchasing good i and $i-1$ if $\mathbf{q} v_i - p_i = \mathbf{q} v_{i-1} - p_{i-1}$, i.e. if

$$\mathbf{q} = \mathbf{q}_i \equiv \frac{p_i - p_{i-1}}{v_i - v_{i-1}} \quad (2.1)$$

Assume that in equilibrium the indifferent consumers are ranked as follows: $\mathbf{q} < \mathbf{q}_1 < \mathbf{q}_2 < \dots < \bar{\mathbf{q}}$. Below it will be checked whether this assumption is indeed satisfied. Market demand for each good i , $i=1 \dots n$, is then positive and given by the mass of consumers with a taste parameter $\mathbf{q}\hat{\mathbf{I}} (\mathbf{q}_i, \mathbf{q}_{i+1}]$, i.e.

$$q_i = (F(\mathbf{q}_{i+1}) - F(\mathbf{q}_i))N \quad (2.2)$$

where for consistency of notation $\mathbf{q}_{n+1} \equiv \bar{\mathbf{q}}$, so that $F(\mathbf{q}_{n+1}) = 1$.⁴

There are n firms. Each firm i , $i = 1 \dots n$, sells a distinct good i at a marginal cost $c_i = c(v_i)$, which is independent of output but increasing and convex in quality. Prices are determined as follows. The price of the outside good, p_0 , is exogenously given, say on a perfectly competitive low quality market. The prices of goods i , $i = 1 \dots n$, are determined collusively from the maximization of the firms' joint profits:

$$\max_{p_1 \dots p_n} \sum_{i=1}^n (p_i - c_i) q_i$$

Although firms may in principle also choose the qualities of their products, I consider these choices as exogenous at the pricing stage. The justification is that firms can adjust prices faster than qualities. Notice that the qualities v_i , influencing both marginal cost and

⁴ The assumption that $\mathbf{q} < \mathbf{q}_1$ implies that market demand for the outside good is also positive in equilibrium. The results in this paper continue to hold for the alternative case in which no consumers would buy the outside good in equilibrium.

demand, are the only exogenous variables (other than p_0) in the model.⁵ The identification of monopoly power should hence be based on comparative statics in quality.

3. Reduced form pricing equations

The first-order conditions for joint profit maximization, defining a collusive pricing equilibrium are:

$$\begin{aligned} & -(p_1 - c_1) \left(\frac{f(\mathbf{q}_2)}{v_2 - v_1} + \frac{f(\mathbf{q}_1)}{v_1 - v_0} \right) + (p_2 - c_2) \frac{f(\mathbf{q}_2)}{v_2 - v_1} + F(\mathbf{q}_2) - F(\mathbf{q}_1) = 0, \\ & \quad \quad \quad -(p_i - c_i) \left(\frac{f(\mathbf{q}_{i+1})}{v_{i+1} - v_i} + \frac{f(\mathbf{q}_i)}{v_i - v_{i-1}} \right) \\ & \quad \quad \quad + (p_{i+1} - c_{i+1}) \frac{f(\mathbf{q}_{i+1})}{v_{i+1} - v_i} + (p_{i-1} - c_{i-1}) \frac{f(\mathbf{q}_i)}{v_i - v_{i-1}} + F(\mathbf{q}_{i+1}) - F(\mathbf{q}_i) = 0 \end{aligned}$$

for $i = 2 \dots n - 1$, and

$$-(p_n - c_n) \frac{f(\mathbf{q}_n)}{v_n - v_{n-1}} + (p_{n-1} - c_{n-1}) \frac{f(\mathbf{q}_n)}{v_n - v_{n-1}} + 1 - F(\mathbf{q}_n) = 0.$$

The system of n first-order conditions can be solved to obtain n reduced form pricing equations, writing price as a function of the qualities solely. The solution method follows two steps. First a solution for the indifferent consumers \mathbf{q}_i is derived. This solution is then used to derive the reduced form pricing equations.

The n -th first-order condition can be rewritten as:

$$p_n - c_n = p_{n-1} - c_{n-1} + \frac{1 - F(\mathbf{q}_n)}{f(\mathbf{q}_n)} (v_n - v_{n-1})$$

⁵ For econometric purposes, it is sufficient to view the qualities v_i as predetermined, rather than as exogenous. They capture the effects of some "truly exogenous" variables, either influencing marginal cost (e.g. factor prices) or demand.

This may be substituted in the $(n - 1)$ -th first-order condition to obtain a similar expression for $p_{n-1} - c_{n-1}$. Repeating this substitution gives the following recursive system for $i = 1 \dots n$:

$$p_i - c_i = p_{i-1} - c_{i-1} + \frac{1 - F(\mathbf{q}_i)}{f(\mathbf{q}_i)}(v_i - v_{i-1}).$$

where, for consistency of notation, $c_0 \equiv p_0$ refers to the price of the outside good. This can be rewritten as:

$$\frac{c_i - c_{i-1}}{v_i - v_{i-1}} = \mathbf{q}_i - \frac{1 - F(\mathbf{q}_i)}{f(\mathbf{q}_i)} \equiv g(\mathbf{q}_i).$$

Assume the function $g(x)$ is monotonically increasing. This assumption is satisfied for many distribution functions, including the uniform, the Pareto, the exponential, the normal and the logistic. This then yields the following unique solution for the taste parameter of the indifferent consumers $\mathbf{q}_i = 1 \dots n$:

$$\mathbf{q}_i = g^{-1}\left(\frac{c_i - c_{i-1}}{v_i - v_{i-1}}\right), \quad (3.1)$$

where $g^{-1}(y)$ is the inverse function of $g(x)$.

The reduced form demand equations are now easily derived by substituting the solutions for \mathbf{q}_i , given by (3.1), in (2.2). The derivation of the reduced form pricing equations requires just a little extra work. Given initial values for the quality and price of the outside good, v_0 and $p_0 \equiv c_0$, the price of good $i=1 \dots n$, is recursively determined from

$$p_i = p_{i-1} + \mathbf{q}_i(v_i - v_{i-1}),$$

as implied by (2.1). Substituting the solutions for \mathbf{q}_i then yields the desired reduced form collusive pricing equations:

$$p_i = p_o + g^{-1}\left(\frac{c_1 - p_o}{v_1 - v_o}\right)(v_1 - v_o) + \sum_{j=2}^i g^{-1}\left(\frac{c_j - c_{j-1}}{v_j - v_{j-1}}\right)(v_j - v_{j-1}). \quad (3.2)$$

It remains to check whether the maintained assumption that all goods (including the outside good) have positive market shares in equilibrium is indeed satisfied, i.e. whether $\mathbf{q} < \mathbf{q}_1 < \mathbf{q}_2 < \dots < \mathbf{q}_n < \bar{\mathbf{q}}$. From the solution for \mathbf{q}_i and the fact that $g^{-1}(x)$ is monotonically increasing, it follows that $\mathbf{q}_i < \mathbf{q}_{i+1}$ for $i = 1 \dots n-1$ if $(c_i - c_{i-1}) / (v_i - v_{i-1}) < (c_{i+1} - c_i) / (v_{i+1} - v_i)$. This is the case given the assumption that marginal cost $c_i = c(v_i)$ is increasing and convex in quality v_i . Similarly, it follows that $\mathbf{q}_n < \bar{\mathbf{q}}$ if $(c_n - c_{n-1}) / (v_n - v_{n-1}) < g(\bar{\mathbf{q}}) = \bar{\mathbf{q}}$. Finally, it can be verified that $\mathbf{q} < \mathbf{q}_1$ if $\mathbf{q} - 1 / f(\mathbf{q}) < (c_1 - p_0) / (v_1 - v_0)$.

4. Comparative statics in quality

Recall that the only exogenous variables in the model are the qualities v_i , which influence both demand and marginal cost. The tests for the presence of monopoly power are correspondingly based on the comparative statics predictions of qualities on prices. These can be easily computed using the reduced form pricing equations (3.2). I demonstrate that the comparative statics in the presence of monopoly power are likely to be distinct from the comparative statics under more competitive conduct.

Using (3.2), the following comparative statics can be computed:

$$\frac{\mathcal{J} p_i}{\mathcal{J} c_k} = \frac{1}{g'(\mathbf{q}_k)} - \frac{1}{g'(\mathbf{q}_{k+1})}, \quad \frac{\mathcal{J} p_i}{\mathcal{J} v_k} = -\frac{g(\mathbf{q}_k) - g'(\mathbf{q}_k)\mathbf{q}_k}{g'(\mathbf{q}_k)} + \frac{g(\mathbf{q}_{k+1}) - g'(\mathbf{q}_{k+1})\mathbf{q}_{k+1}}{g'(\mathbf{q}_{k+1})}, \quad k = 1 \dots i-1$$

$$\frac{\mathcal{J} p_i}{\mathcal{J} c_i} = \frac{1}{g'(\mathbf{q}_i)}, \quad \frac{\mathcal{J} p_i}{\mathcal{J} v_i} = -\frac{g(\mathbf{q}_i) - g'(\mathbf{q}_i)\mathbf{q}_i}{g'(\mathbf{q}_i)}$$

$$\frac{\mathcal{J} p_i}{\mathcal{J} c_k} = \frac{\mathcal{J} p_i}{\mathcal{J} v_k} = 0, \quad k = i + 1 \dots n$$

This can be used to calculate the total effect of a quality v_k on a price p_i

$$\frac{dp_i}{dv_k} = \frac{\mathcal{J} p_i}{\mathcal{J} v_k} + \frac{\mathcal{J} p_i}{\mathcal{J} c_k} c'(v_k), \quad i, k = 1 \dots n$$

These comparative statics yield a strong prediction and a weak prediction of monopoly power.

Strong prediction of monopoly power: The price of product i , p_i , does not depend on the qualities $v_{i+1} \cdots v_n$.

Weak prediction of monopoly power: If $g''(x) = 0$, then the price of product i , p_i , does not depend on the qualities $v_1 \cdots v_{i-1}$.

The strong prediction of monopoly power follows straightforward from the above computations. The weak prediction follows from the above computations and the fact that $g'(\mathbf{q}_k) = g'(\mathbf{q}_{k+1})$ and $g(\mathbf{q}_k) - g'(\mathbf{q}_k)\mathbf{q}_k = g(\mathbf{q}_{k+1}) - g'(\mathbf{q}_{k+1})\mathbf{q}_{k+1}$ if $g''(x) = 0$. Notice that the weak prediction applies to several frequently used distributions of the taste parameter θ , including the uniform, the Pareto and the exponential. In the Appendix this is illustrated by a more general distribution function for which $g''(x) = 0$, nesting the above three distributions as special cases.

An important question is whether there exist interesting economic models of equilibrium behavior that yield *different* predictions than the strong and weak predictions of monopoly power derived above. If not, then not much interesting can be learned from rejection of the predictions of monopoly power.

Consider first the simple model of perfect competition. In this model price equals marginal cost, i.e. $p_i = c_i = c(v_i)$. As in Panzar and Rosse (1987), the model of perfect competition then yields the same prediction as the model with monopoly power: the qualities of firm i 's competitors do not influence the price of firm i .⁶ However, the equilibrium notion of perfect competition is not a very plausible one when there are only a finite, and typically small, number of firms in the industry. A more sensible equilibrium notion that captures *strategic interaction* among a finite number of firms is the Bertrand-Nash equilibrium. This equilibrium is defined by the conditions that each firm unilaterally maximizes its own profit with respect to its own price, given the prices set by its competitors. Only if the number of firms goes to infinity the pricing equations reduce to

⁶ As noted by Panzar and Rosse (1987), perfect competition and monopoly have in common that there is no strategic interaction. This may be the reason why they yield the same comparative statics.

the marginal cost equations of perfect competition. In the more plausible case with a finite number of firms the reduced form pricing equations do not have a simple solution. The simple special cases of two, three or four firms with a uniform or an exponential distribution of the taste parameter \mathbf{q} nevertheless all yield the following prediction of Bertrand-Nash equilibrium, in sharp contrast with the predictions of monopoly power.⁷

Prediction of Bertrand-Nash equilibrium: The price of product i may depend on all qualities $v_1 \dots v_n$, even if $g''(x) = 0$. Furthermore, the qualities $v_{i+1} \dots v_n$ have a positive impact on p_i , whereas the qualities $v_1 \dots v_{i-1}$ may have a negative or positive impact on p_i .

Intuitively, an increase in the quality of a higher quality competitor j , $j > i$, both increases j 's marginal cost and decreases j 's substitutability for i , so that the price of product i , p_i , increases under Bertrand competition. In contrast, an increase in the quality of a lower quality competitor j , $j < i$, increases j 's marginal cost but also increases j 's substitutability for i , so that the price of product i , p_i , may either decrease or increase under Bertrand competition.

Note that the Bertrand-Nash equilibrium is certainly not the only plausible alternative to the equilibrium with monopoly power. In particular, there may be equilibria that lie somewhere in between these two extremes.⁸ These "in-between" equilibria are likely to yield similar qualitative to the predictions of the Bertrand-Nash equilibrium, although the predictions may not be as clear-cut. To simplify the discussion below I will focus attention to the two extremes.

5. Empirical tests for monopoly power

The above findings suggest to estimate a general regression model in which the price p_i is allowed to depend on all qualities v_k . Take the following linearized approximation:

$$h(p_i) = \mathbf{b}_{i,1}v_1 + \dots + \mathbf{b}_{i,i-1}v_{i-1} + v_i + \mathbf{a}_{i,i+1}v_{i+1} + \dots + \mathbf{a}_{i,n}v_n + \hat{\mathbf{I}}_i, \quad (5.1)$$

⁷ The calculations of the given examples are straightforward, and available on request.

⁸ Formally, such equilibria may be modeled in a repeated game in which the discount factor is not sufficiently large for the monopoly solution to be sustainable, but sufficiently large for an equilibrium in between the monopoly and the Bertrand-Nash solution to be sustainable.

where $h(p_i)$ is an increasing transformation of p_i , and where $\hat{\mathbf{I}}_i$ is a "prediction error", possibly including an error in measuring price (e.g. due to unobserved discounts, as in Bresnahan, 1987). Measure the qualities v_i by a vector of physical characteristics, x_i , according to

$$v_i = x_i \mathbf{g} \quad (5.2)$$

where \mathbf{g} is a vector of parameters to be estimated.

The hypotheses to be tested are the predictions of monopoly power. If the strong prediction of monopoly power holds, then all $\mathbf{a}_{i,j} = 0$. If in addition the weak prediction of monopoly power holds, then all $\mathbf{a}_{i,j} = \mathbf{b}_{i,j} = 0$, so that $h(p_i) = v_i + \hat{\mathbf{I}}_i = x_i \mathbf{g} + \hat{\mathbf{I}}_i$, which is just the popular *hedonic* specification.⁹ If the hypotheses of monopoly power are rejected, then the alternative hypothesis of Bertrand-Nash equilibrium holds. In this case the prediction of Bertrand-Nash equilibrium, based on the examples and intuition discussed in the previous section, suggests that $\mathbf{a}_{i,j} > 0$, whereas the sign of $\mathbf{b}_{i,j}$ is ambiguous.

Unfortunately, to estimate (5.1) a tremendous amount of data is required. Even if quality is directly observed (or γ is known), there remain $n-1 \times n$ parameters to be estimated (the $\mathbf{a}_{i,j}$ and $\mathbf{b}_{i,j}$). A particular market at a particular period in time consists of just n observations, implying the need for data on a very large number of markets and/or time periods. Furthermore, the parameters may not even be stable over the markets or time periods. Clearly, some structure should be imposed on the parameters $\mathbf{a}_{i,j}$ and $\mathbf{b}_{i,j}$ to make estimation possible. In principle, this structure may be derived explicitly from the model of vertical product differentiation, after imposing specific functional form assumptions, and after defining an equilibrium notion, covering the monopoly equilibrium

⁹ The hedonic regression model may therefore not only be founded in a perfectly competitive framework, as in Rosen (1973), but also in a perfect monopoly framework. For example, the frequently used hedonic regression $\ln(p_i) = v_i + \hat{\mathbf{I}}_i$ is the monopoly solution if the distribution function $F_m(x)$ given in the Appendix by (A.1) holds, and the marginal cost function is given by $c(v_i) = (1+m)(\exp v_i - p_0) + p_0 - (\bar{\mathbf{q}} - \mathbf{q} + \mathbf{m}\mathbf{q})(v_i - v_0)$, as may be easily verified from (A.2). This marginal cost function is increasing for $v_i > \ln(\bar{\mathbf{q}} - \mathbf{q} + \mathbf{m}\mathbf{q}) / (1+m)$, and convex, as required.

and some other possible equilibria, such as the Bertrand-Nash, as special cases. However, such an approach would share many of the problems of the structural form approach: it would quickly become computationally intractable, and the imposed structure would remain partly arbitrary anyway, as it depends on the specific functional form assumptions. It are precisely these problems that I am trying to avoid here!

I therefore follow an alternative, more flexible approach and directly impose various alternative restrictions on the parameters $\mathbf{a}_{i,j}$ and $\mathbf{b}_{i,j}$ in (5.1). More specifically, I propose to estimate the following alternative regression models to test for the presence of monopoly power.

Regression 1: $\ln(p_i) = \mathbf{b}v_{i-1} + v_i + \mathbf{a}v_{i+1} + \epsilon_i$

Regression 2: $\ln(p_i) = \mathbf{b}_2v_{i-2} + \mathbf{b}_1v_{i-1} + v_i + \mathbf{a}_1v_{i+1} + \mathbf{a}_2v_{i+2} + \hat{\mathbf{I}}_i$

Regression 3: $\ln(p_i) = \mathbf{b}^2v_{i-2} + \mathbf{b}v_{i-1} + v_i + \mathbf{a}v_{i+1} + \mathbf{a}^2v_{i+2} + \hat{\mathbf{I}}_i$

Regression 4:

$$\ln(p_i) = \mathbf{b}^{i-1}v_1 + \mathbf{b}^{i-2}v_2 + \dots + \mathbf{b}v_{i-1} + v_i + \mathbf{a}v_{i+1} + \dots + \mathbf{a}^{n-i-1}v_{n-1} + \mathbf{a}^{n-i}v_n + \hat{\mathbf{I}}_i$$

In all these regressions price enters logarithmically, i.e. $h(p_i) = \ln(p_i)$. The regressions then generalize one of the most frequently used hedonic specifications, i.e. $\ln(p_i) = v_i + \hat{\mathbf{I}}_i$. I also experimented with specifications in which $h(p_i) = \sqrt{p_i}$, but this did not affect the empirical results.¹⁰

The structure imposed on the parameters $\mathbf{a}_{i,j}$ and $\mathbf{b}_{i,j}$ is based on the intuition that *if* the presence of monopoly power is rejected, i.e. *if* $\mathbf{a}_{i,j}$ or $\mathbf{b}_{i,j}$ are different from zero, then especially the qualities of product i 's "close" competitors are likely to influence the price of product i . It can be verified that this is indeed the case under the alternative hypothesis of Bertrand competition, using the above mentioned examples of two, three or four firms with a uniform or exponential distribution of the taste parameter \mathbf{q} . The first regression model imposes the most restrictive structure: it allows product i 's price to be a function

¹⁰ I found it desirable to restrict experimentation to *concave* transformations of price. As can be verified, this restriction is natural given that marginal cost should be convex in quality for all products to have positive markets shares.

only of its closest lower and higher quality variant. Regression 2 also allows product i 's price to be a function of its second closest lower and higher quality variant. Regression 3 is a special case of regression 2, restricting the influence of the two lower and higher quality variants to be geometrically declining. Regression 4 applies this geometrically declining sequence to all lower and higher quality variants of product i .

Using (5.2), regressions 1, 2, and 3 can be easily estimated using some nonlinear least squares estimator. To estimate regression 4 I apply a transformation similar to the Koyck transformation. As shown in the Appendix regression 4 can be transformed into:

$$(1 + \mathbf{ab})(1 - L_i - H_i) \ln(p_i) = (1 - \mathbf{ab})v_i +$$

$$\mathbf{b}(1 - L_i) \ln(p_{i-1}) + \mathbf{a}(1 - H_i) \ln(p_{i+1}) + \hat{\mathbf{I}}_i(1 + \mathbf{ab}) - \mathbf{b}(1 - L_i)\hat{\mathbf{I}}_{i-1} - \mathbf{a}(1 - H_i)\hat{\mathbf{I}}_{i+1},$$

where L_i is a dummy variable equal to 1 if the product is of the lowest quality (i.e. v_l) and zero otherwise; and H_i is a dummy variable equal to 1 if the product is of the highest quality (i.e. v_n) and zero otherwise. Note that this regression is autoregressive: it contains both a lag and a lead of the endogenous variable p_i . Furthermore, the error term is serially correlated. Consequently, a least squares estimator is inconsistent and an instrumental variable estimator is necessary to estimate regression 4. I have used the elements of the vector of physical characteristics, x_i , as well as the lags and the leads of these elements as instruments.

Regressions 1, 2, 3 and 4 require a "correct" ranking of the qualities v_i . If quality is directly observed this can be easily done. More generally, however, the qualities need to be estimated using $x_i\gamma$. In this case I will require the ranking of the qualities to be *consistent* with the estimates in the following sense: the ranking of the qualities as implied by the estimates should not contradict the ranking that was assumed to obtain the estimates. To obtain a consistent ranking I use the following procedure. In a first stage I set $\mathbf{a}_{ij} = \mathbf{b}_{ij} = 0$ in (5.1) and estimate the model. An initial estimate of the qualities $v_i = x_i\gamma$ is then obtained, allowing to order the qualities. Then a second stage begins in which the model is re-estimated, including the parameters \mathbf{a}_{ij} and \mathbf{b}_{ij} . The new estimates can then be used to re-order the qualities once again. This procedure is repeated until convergence is reached, i.e. until the qualities do no longer need to be reordered.

6. Two applications

I have used two different samples to illustrate the proposed tests for monopoly power: the market for spreadsheets in the U.S. (1986-1991) and the market for "engine variants" in the 1990 French car market.¹¹

The first sample covers 6 years of the U.S. spreadsheet market, with about 15 spreadsheet programs per year. This yields a panel of 91 spreadsheet observations for the period 1986-1991. This sample is used to test the hypothesis of monopoly power across spreadsheet programs sold at a given time period. The following variables are used here.¹² The endogenous variable is LPRICE, the log of the list price of a single copy of the spreadsheet program. The exogenous variables are several physical characteristics, measuring the quality of the spreadsheet. The variable LMINRC is the log of the minimum of the maximum number of rows and columns that the spreadsheet can handle. The dummy variable LOTUS equals one if the program is produced by Lotus Development Corporation, and equals zero otherwise. The dummy variable GRAPHS equals one if the program can perform all basic graphs. WINDOW is a variable equal to two if the maximum number of windows on the screen is sixteen or more; equal to one if this maximum is from two to fifteen; and equal to zero otherwise. LOCOMP is a dummy variable equal to one if the program is compatible with the Lotus (WKS, WK1) format. EXTDAT is a dummy variable equal to one if the program provides links to external data bases. LANCOM is a dummy variable equal to one if the program can link independent users through a local area network. LINKING is a dummy variable equal to one if the values in several worksheets can be updated at the same time. In addition to these physical characteristics there are 5 time dummy variables TIME87, TIME88, TIME89, TIME90, TIME91.

Using the above variables, Table 1 presents estimates of the vector γ in (5.1) and (5.2), assuming $h(p_i) = \ln(p_i)$ and restricting $\mathbf{a}_{ij} = \mathbf{b}_{ij} = 0$. Recall that this is just a simple hedonic regression, which holds under the null hypothesis of monopoly power.

¹¹ The data on spreadsheets were provided by Neil Gandal. The data on the French car market were collected from the catalogues *Automobil Revue* and *l'Auto-Journal*.

¹² See Gandal (1994) for a more detailed discussion of these data.

The included variables in this regression are selected from a larger set of variables, based on their significant contribution to the regression.¹³ The parameter estimates of the physical characteristics all have the expected positive sign. The time dummy variables have negative parameter estimates, indicating that the "quality adjusted" price of spreadsheets is decreasing over time.

The second sample consists of 38 popular European models sold in the 1990 French car market. The Renault Clio and the Volkswagen Golf are examples of these models. Each model is sold in about 5 different engine variants. This yields a panel of 196 observations on engine variants. This sample is used to test the hypothesis of monopoly power across the different engine variants sold by the same given car model.¹⁴ The following data are used. The endogenous variable is LPRICE, which is the log of the list price of a variant. The variable WEIGHT is the total weight of the car, including all equipment (in ton). WIDTH is the maximum width (in m). HORSEPOWER is the variant's maximum horsepower (in 100 kilowatt). DIESEL is a dummy variable equal to one if the variant has a diesel engine. CYLINDER is the cylinder volume (in dm^3). Different engine variants of the same model have the same width and approximately the same weight. They differ in horsepower, cylinder volume and diesel. A *base model* is defined as the variant of a particular model with the lowest specification of horsepower and cylinder volume, and without diesel. I did not include dummy variables to estimate the "model-specific effects" (analogous to the time dummies in the sample of spreadsheets). This uses up many degrees of freedom (38), and the model-specific effects are captured fairly well by the included model-specific characteristics WEIGHT and WIDTH anyway.

Using the above variables Table 2 presents estimates of γ in (5.1) and (5.2), again assuming $h(p_i) = \ln(p_i)$ and restricting $\mathbf{a}_{ij} = \mathbf{b}_{ij} = 0$. These variables are selected from a

¹³ The larger set of variables is discussed in Gandal (1994). It is worth mentioning that it was possible to replicate his results. As shown by Gandal (1994), the used specification is not entirely stable over time. The parameters of the variables LMINRC, LANCOM and LINKING differ significantly over two separate sample periods (1986-1988 versus 1989-1991). I therefore also applied the tests for monopoly power to the "unstable" specification, and obtained similar results.

¹⁴ Competition across different models will be ignored here. I come back to this restriction in section 7.

regression with a larger set of variables, based on their significance. This larger set also included the characteristics LENGTH, HEIGHT, NUMCYL (number of cylinders), and firm dummy variables (for Fiat, Ford, GM, PSA, Renault and Volkswagen).¹⁵ All parameter estimates have the expected positive sign.

The hedonic parameter estimates in Tables 1 and 2 are used to obtain an initial ranking of the qualities. In the first sample the qualities of all spreadsheets in each given year are ranked. In the second sample the qualities of all engine variants of each given car model are ranked. Then an initial estimate is obtained of the parameters in Regressions 1, 2, 3, and 4. Based on these estimates a new ranking of qualities is obtained. Regressions 1, 2, 3 and 4 are then re-estimated until a re-ordering is no longer required.¹⁶ The estimates of the parameters \mathbf{a} and \mathbf{b} (and \mathbf{a}_i and \mathbf{b}_i in the case of regression 2) are presented on Tables 3 and 4. To save space, the estimates of the other parameters are not presented. They generally did not differ very much from the estimates in Tables 1 and 2.

The results in Table 3 are in stark contrast with the results in Table 4. In Table 3, the market for spreadsheets, almost all estimates of \mathbf{a} and \mathbf{b} are significantly different from zero, with the exception of some of the estimates for regression 2. All significant estimates of \mathbf{a} are positive; all significant estimates of \mathbf{b} are negative. The insignificant estimates in regression 2 may be due to the little structure imposed in this regression. This is suggested by the significant estimate of \mathbf{a} and \mathbf{b} in regression 3, which is a restricted version of regression 2. In contrast, in Table 4, the market for "engine variants", the estimates of the parameters \mathbf{a} and \mathbf{b} are usually not significant. Furthermore, the magnitude of the estimates of \mathbf{a} and \mathbf{b} is much smaller in the market for engine variants (Table 4) than in the market for spreadsheets (Table 3).¹⁷

¹⁵ The stability of the parameters of the included variables was tested by running two separate (hedonic) regressions, one for a sample of only French cars, one for a sample of only foreign cars. All parameters turned out to be stable.

¹⁶ In the case of engine variants two iterations were required. In the case of spreadsheets convergence was not always obtained. However, the parameter estimates did not alter very much over iterations. In case of no convergence the estimates after two iterations are presented.

¹⁷ Some care had to be taken to allow for a reasonable comparison of the magnitudes of \mathbf{a} and \mathbf{b} . I multiplied the prices of spreadsheets by a constant factor, determined such that the average price of spreadsheets equals the average price of engine variants. In a hedonic regression, with the

These contrasting results may be interpreted as follows. The presence of monopoly power is significantly rejected in the market for spreadsheets. This follows from the fact that the characteristics of product i 's competitors significantly influence the price of product i . Note that the signs of \mathbf{a} (positive) and \mathbf{b} (negative) are consistent with the alternative hypothesis of Bertrand competition. The presence of monopoly power over price on different engine variants of a given car model cannot be rejected by the data.

The empirical results are consistent with several facts. First, the results are consistent with the ownership structure in both markets. Different spreadsheets programs are usually owned by different firms, whereas different engine variants of a specific car model are of course owned by the same firm. The rejection of monopoly power in the market for spreadsheets is also consistent with the relatively large number of active firms (usually between ten or fifteen during each year) and the high annual entry and exit rates. These factors probably make collusion difficult. Finally, the presence of monopoly power in the market for engine power is consistent with Scherer's (1980, p. 394) observation (for the American market). He quotes a "leaked" memorandum on the 1966 American Ford Galaxie sedan, stating that the wholesale price exceeds accounting cost by up to 293 percent for the high quality engine variants compared to only 17 percent for the lowest quality variant, a price discrimination practice which is easier to explain in the presence of monopoly power than in the absence of it.

The consistency of the empirical results with the *a priori* evidence on both markets is encouraging. It suggests that the developed empirical tests can also be used in other applications, in which it is less obvious *a priori* whether or not monopoly power is present. For policy purposes one may then view the tests as one extra piece of possible evidence for the presence (or absence) of monopoly power.

$\ln(\text{PRICE})$ as the dependent variable, this multiplication of course only affects the constant in the vector γ . This is no longer the case in regressions 1, 2, 3 and 4, because there is no "true" constant term in these regressions. It was actually not possible to estimate such a "true" constant term, given the included constant in the vector γ .

7. Suggested extensions

The tests for monopoly power proposed in this paper are based on a fairly general model of vertical product differentiation, covering past theoretical and empirical applications as special cases, for example Bresnahan's (1987) analysis of collusive behavior in the American car market between 1954-1956. Nevertheless, the results ought to be interpreted with care. Some important assumptions have still been made. These should be relaxed in further work.

The first assumption is that product differentiation occurs in just one quality dimension. This is in fact equivalent to assuming several quality dimensions as long as consumer preferences for quality are *perfectly correlated* over these dimensions. However, it is possible that such a perfect correlation does not hold in the above considered samples. In both the market for spreadsheets and the market for engine variants there may be two main quality dimensions. In the market for spreadsheets, a first dimension is "power", as captured by the variables LMINRC, GRAPHS, WINDOW and LINKING. A second dimension is "network accessibility", as captured by the variables LOCOMP, EXTDAT and LANCOM. Consumer preferences may not be perfectly correlated over these two quality dimensions. Similarly, in the market for "engine variants" a first quality dimension is engine power, as captured by HORSEPOWER and CYLINDER. The variable DIESEL captures a second quality dimension of an engine variant, and it is again not clear whether consumer preferences are perfectly correlated over these two dimensions. The assumption that products are differentiated in just one quality dimension is empirically translated in the assumption that it is possible to unambiguously rank all products according to their 'quality'. It would be a very interesting topic for future research to analyze how empirical tests would generalize if such an unambiguous ranking is not possible because of the presence of more than one (say two) quality dimensions.

The second assumption made in the analysis is that each vertically differentiated market can be treated as an independent market, without substitution across markets. In the case of spreadsheets sold in a given time period, this assumption means that there is no intertemporal substitution. In the case of engine variants of a given car model, the

assumption means that there is no substitution between different car models. Even though the above mentioned evidence by Scherer (1980) suggests that this assumption may not be too unreasonable for the variants other than the base models,¹⁸ I remained worried with this assumption. I therefore repeated the tests for a limited sample of only the French cars. One may expect that the assumption of no substitution between different models is more reasonable for domestic firms. Indeed, using a structural form model of competition between base models Verboven (1995) shows that French models have a lot of domestic market power, in contrast to the foreign firms. The empirical results based on this limited sample turned out to be quite similar to those of the full sample.

Of course, the need for relaxing the assumption of independent markets and of one-dimensional vertical differentiation -- remains, in order to widen the scope for interesting economic applications.

A. Appendix

A class of distributions for which $g''(x) = 0$.

Consider the following distribution function for the taste parameter \mathbf{q} , $F_m(x)$:

$$F_m(x) \equiv 1 - \left(1 - m \frac{x - \underline{\mathbf{q}}}{\bar{\mathbf{q}} - \underline{\mathbf{q}}} \right)^{1/m}, \quad (\text{A.1})$$

with $\mathbf{q}\hat{\mathbf{l}} \left[\underline{\mathbf{q}}, \underline{\mathbf{q}} + (\bar{\mathbf{q}} - \underline{\mathbf{q}}) / m \right]$ if $m > 0$, and $\mathbf{q}\hat{\mathbf{l}} \left[\underline{\mathbf{q}}, \infty \right]$, if $m \leq 0$.¹⁹ The uniform distribution obtains if $m = 1$; the exponential obtains if $m = 0$; the Pareto obtains if $m = -\bar{\mathbf{q}} = -1/(1+\lambda)$ and $\underline{\mathbf{q}} = 0$. It is easy to verify that $g''(x) = 0$ for this distribution. Furthermore, one can use (3.2) to find the reduced form pricing equation $F(x) = F_m(x)$:

$$p_i = p_0 + \frac{1}{1+m} (c(v_i) p_0 + (\bar{\mathbf{q}} - \underline{\mathbf{q}} + m\underline{\mathbf{q}}) (v_i - v_0)) \quad (\text{A.2})$$

¹⁸ The fact that car manufacturers often only advertize prices of their base models, and not of the other variants, reinforces this suggestive evidence. See Diamond (1971) for a provocative model of competition when consumers do not observe prices costlessly.

Clearly, the price of product i does not depend on the quality of product i 's competitors in this example.

Transformation of regression 4.

To transform regression 4 note first that for $i = 1 \dots n - 1$

$$\ln(p_i) - \mathbf{a} \ln(p_{i+1}) = (1 - \mathbf{ab}) (\mathbf{b}^{i-1} v_1 + \mathbf{b}^{i-2} v_2 + \dots + \mathbf{b} v_{i-1} + v_i) + \hat{\mathbf{I}}_i - \mathbf{a} \hat{\mathbf{I}}_{i+1},$$

This yields for observations $i = 2 \dots n - 1$

$$(\ln(p_i) - \mathbf{a} \ln(p_{i+1}) - \mathbf{b}(\ln(p_{i-1}) - \mathbf{a} \ln(p_i))) = (1 - \mathbf{ab})v_i + \hat{\mathbf{I}}_i - \mathbf{a} \hat{\mathbf{I}}_{i+1} - \mathbf{b}(\hat{\mathbf{I}}_{i-1} - \mathbf{a} \hat{\mathbf{I}}_i),$$

or

$$(1 + \mathbf{ab})(\ln(p_i) - \mathbf{a} \ln(p_{i+1})) = (1 - \mathbf{ab}) v_i + \mathbf{b}(\ln(p_{i-1}) - \mathbf{a} \ln(p_i)) + \hat{\mathbf{I}}_i(1 + \mathbf{ab}) - \mathbf{b} \hat{\mathbf{I}}_{i-1} + \mathbf{a} \hat{\mathbf{I}}_{i+1}.$$

Similarly, for the first and the n -th observation:

$$\ln(p_1) = (1 - \mathbf{ab})v_1 + \mathbf{a} \ln(p_2) + \hat{\mathbf{I}}_1 - \mathbf{a} \hat{\mathbf{I}}_2$$

$$\ln(p_n) = (1 - \mathbf{ab})v_n + \mathbf{b} \ln(p_{n-1}) + \hat{\mathbf{I}}_n - \mathbf{b} \hat{\mathbf{I}}_{n-1}.$$

Define a dummy variable $L_i = 1$ if the product is of the lowest quality (the first observation), and $L_i = 0$ otherwise. Similarly define $H_i = 1$ if the product is of the highest quality (the n -th observation) and $H_i = 0$ otherwise. Then it is possible to write regression 4, for $i = 1 \dots n$ as:

$$(1 + \mathbf{ab})(1 - L_i - H_i) \ln(p_i) = (1 - \mathbf{ab})v_i +$$

$$\mathbf{b}(1 - L_i) \ln(p_{i-1}) + \mathbf{a}(1 - H_i) \ln(p_{i+1}) + \hat{\mathbf{I}}_i(1 + \mathbf{ab}) - \mathbf{b}(1 - L_i) \hat{\mathbf{I}}_{i-1} - \mathbf{a}(1 - H_i) \hat{\mathbf{I}}_{i+1}.$$

¹⁹ Notice a slightly different notation for the upperbound. It does not necessarily coincide with $\bar{\mathbf{q}}$, as it was denoted before.

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Table 1. Hedonic specification Equation (5) with $\alpha_{ij}=\beta_{ij}=0$, Dependent variable ln(PRICE) Spreadsheet programs (91 observations)		
Variable	Parameter	t-statistic
CONSTANT	3.76	12.31
TIME87	-.06	-.38
TIME88	-.44	-2.67
TIME89	-.70	-4.20
TIME90	-.79	-4.90
TIME91	-.85	-5.30
LMINRC	.11	1.59
LOTUS	.56	4.36
GRAPHS	.46	3.51
WINDOW	.17	2.14
LOCOMP	.72	5.28
EXTDAT	.55	4.05
LANCOM	.21	1.65
LINKING	.21	1.91
Std. error of regr.	.39	
R ²	.86	

Note: these results coincide with Gandal's (1994) regression 2 and 3.

Table 2. Hedonic specification Equation (5) with $\alpha_{ij}=\beta_{ij}=0$ Dependent variable $\ln(\text{PRICE})$ Engine variants (196 observations)		
Variable	Parameter	t-statistic
CONSTANT	3.39	14.59
WEIGHT	.56	5.56
WIDTH	.46	2.57
HORSEPOWER	.60	15.84
DIESEL	.13	5.66
CYLINDER	.97	2.84
Std. error of regr.	.09	
R^2	.95	

Table 3. Equation (5), alternative specifications Spreadsheet Programs			
		Parameter	t-statistic
Regression 1	α	.046	4.00
	β	-.160	-3.93
Regression 2	α_1	.038	1.14
	α_2	.016	.34
	β_1	-.204	-3.24
	β_2	.139	1.41
Regression 3	α	.035	3.38
	β	-.039	-1.28
Regression 4	α	.052	5.28
	β	-.120	-2.94

Note: standard errors and t-statistics are computed from heteroscedastic consistent matrix.

Table 4. Equation (5), alternative specifications Engine variants			
		Parameter	t-statistic
Regression 1	α	-.007	-1.54
	β	-.005	-1.29
Regression 2	α_1	-.007	-1.68
	α_2	.003	.75
	β_1	-.003	-.89
	β_2	-.001	-.19
Regression 3	α	-.006	-1.48
	β	-.003	-.88
Regression 4	α	-.007	-1.53
	β	-.006	-1.65

Note: standard errors and t-statistics are computed from heteroscedastic-consistent matrix.