

Testing for monopoly power when products are differentiated in quality

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Abstract

This paper proposes a reduced form approach to empirically identify the presence of monopoly power in oligopolies characterized by vertical product differentiation. In a fairly general model I derive the reduced form pricing equation under the hypothesis that firms collude by maximizing their joint profit. A 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 simple tests implied by this result, requiring data only on the prices and the physical characteristics of the products. The tests are applied to the market for spreadsheets in the US (1986-1991) and to the market for 'engine variants' in the 1990 French car market. The empirical results are promising, but also indicate the need for further generalizations of the model.

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1 Introduction

During the past two decades there has been a renewed interest in empirically identifying the presence of market power in selected industries. Much of the literature has focused on estimating structural form models, closely following the recent developments in oligopoly theory.¹ A structural form model of an oligopoly typically consists of a demand equation and a ‘supply’ equation, as determined by the specific equilibrium assumptions. Estimating structural parameters is usually regarded as very appealing because it allows for a clear economic interpretation of the empirical results, and for policy analysis through model simulations.

There are, however, also disadvantages with the structural form approach. 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 functional forms of demand and supply. Furthermore, the structural form approach requires data on *all* endogenous variables in the model, which is not always possible. Finally, the econometric procedures to estimate even simple structural form models are frequently computationally burdensome. A useful complementary approach is therefore often the reduced form approach. This approach writes the endogenous variables such as prices, quantities or revenues as a function of the exogenous variables solely, and then estimates this relationship.

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 derive the reduced form pricing equations under the hypothesis that firms collude by maximizing their joint profit. A 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 simple econometric tests implied by the comparative statics result. The tests require only data on the prices and physical characteristics of the products. These are exactly the same data as in the traditional “hedonic” studies.

I have applied the tests to two different industries: the market for spreadsheets in

¹Two famous contributions are Porter (1984) and Bresnahan (1987). Geroski (1988) and Bresnahan (1989) provide a survey of the literature.

the US (1986-1991) and the market for "engine variants" in the 1990 French car market. The empirical results are encouraging, and consistent with several stylized facts on both 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, the results call for some desirable further generalizations of the model.

Bresnahan (1987) has used a structural model of vertical product differentiation to test for the presence of collusion in the US car market during the mid-fifties. His model is a special case of the model presented in this paper, it requires more data, and it is computationally demanding, as discussed in Berry (1994). It would be interesting to investigate whether the simple tests developed in the present paper would yield similar conclusions as those obtained by Bresnahan (1987).

Most of our current knowledge on market power is based on the empirical results from structural form models. Interest in the testable implications of reduced form models has been relatively scarce. The most notable contribution is by Panzar and Rosse (1987). In a model with monopoly power they discover a testable prediction about the effect of factor prices – or more generally all exogenous variables influencing cost but not demand – on revenues.² They emphasize the generality of their result and the applicability even when data on prices and quantities are not separately available. In principle, their test is applicable to all industries, including industries characterized by product differentiation. In practice, however, industries with product differentiation do often not meet the data requirements to implement the test. In such industries there may only be data available on prices rather than on revenues. More importantly, there may be no data on the exogenous variables that affect cost and not demand, such as factor prices. Even if such data would exist, there may be little variability of these data across products. In industries with product differentiation the available data on the "exogenous" variables are usually the products' physical characteristics. These physical characteristics influence *both* marginal cost and demand, so that Panzar and Rosse's test cannot be applied.³ Consequently, in industries with product differentiation the tests

²They 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.

³More precisely, one may view the products' physical characteristics as predetermined, rather than as exogenous variables. They capture the effects of some underlying 'truly exogenous' variables either influencing cost (such as factor prices) or demand.

developed in this paper, or some variants thereof, may be preferable.

After presenting the model 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, as introduced by Mussa and Rosen (1978).⁴ There are N consumers, all endowed with income y , and $n + 1$ goods, $i = 0 \cdots n$, where good 0 is an outside good. A good i has a quality v_i and is sold at a price p_i . Assume $v_0 < v_1 < \cdots < v_n$. The conditional indirect utility of a consumer of type θ buying product i is given by

$$u_i(\theta) = y + v_i\theta - p_i, \quad i = 1 \cdots n$$

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

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

$$\theta = \theta_i \equiv \frac{p_i - p_{i-1}}{v_i - v_{i-1}}. \quad (1)$$

Assume that in equilibrium the indifferent consumers are ranked as follows: $\theta_1 < \theta_2 < \cdots < \theta_n < \bar{\theta}$. Below it will be checked whether this is indeed the case. Market demand for each good i , $i = 2 \cdots n$, is then positive and given by the mass of consumers with a taste parameter $\theta \in (\theta_i, \theta_{i+1}]$, i.e.

$$q_i = (F(\theta_{i+1}) - F(\theta_i))N$$

where for consistency of notation $\theta_{n+1} \equiv \bar{\theta}$, so that $F(\theta_{n+1}) = 1$. Market demand for good 1 depends on whether or not all consumers are served. If $\underline{\theta} < \theta_1$, not all consumers

⁴Mussa 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.

are served; some of the consumers want to buy the outside good 0. Otherwise, none of the consumers on the interval $[\underline{\theta}, \bar{\theta}]$ wants to buy the outside good. Assume for simplicity that $\underline{\theta} < \theta_1$, i.e. not all consumers are served. The alternative case is the straightforward analogue. Demand for good 1 then is:

$$q_1 = (F(\theta_2) - F(\theta_1))N. \quad (2)$$

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:

$$\max \sum_{i=1}^n (p_i - c_i)q_i.$$

Although firms may in principle also choose the qualities of their products, I consider these choices as exogenous, or predetermined, at the pricing stage. The justification is that firms can adjust prices faster than qualities.

3 Reduced form pricing equations

The first-order conditions defining a collusive pricing equilibrium are:

$$\begin{aligned} -(p_1 - c_1) \left(\frac{f(\theta_2)}{v_2 - v_1} + \frac{f(\theta_1)}{v_1 - v_0} \right) + (p_2 - c_2) \frac{f(\theta_2)}{v_2 - v_1} + F(\theta_2) - F(\theta_1) &= 0, \\ -(p_i - c_i) \left(\frac{f(\theta_{i+1})}{v_{i+1} - v_i} + \frac{f(\theta_i)}{v_i - v_{i-1}} \right) \\ + (p_{i+1} - c_{i+1}) \frac{f(\theta_{i+1})}{v_{i+1} - v_i} + (p_{i-1} - c_{i-1}) \frac{f(\theta_i)}{v_i - v_{i-1}} + F(\theta_{i+1}) - F(\theta_i) &= 0 \end{aligned}$$

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

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

The system of n first-order conditions can be solved to obtain n reduced form pricing equations. The solution method follows two steps. First a solution for the indifferent consumers θ_i is derived. This solution is then used to derive the reduced form pricing equations (as well as the reduced form demand equations).

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

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

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 $i = 2 \cdots n$:

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

This can be rewritten as:

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

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 solution for the taste parameter of the indifferent consumers θ_i , $i = 2 \cdots n$:

$$\theta_i = g^{-1} \left(\frac{c_i - c_{i-1}}{v_i - v_{i-1}} \right), \quad (3)$$

where $g^{-1}(y)$ is the inverse function of $g(x)$. The solution for θ_1 is similarly determined using the first first-order condition to find:

$$\theta_1 = g^{-1} \left(\frac{c_1 - p_0}{v_1 - v_0} \right).$$

The reduced form demand equations are now easily derived by substituting the solutions for θ_i in (2). The derivation of the reduced form pricing equation requires a little extra work. Given initial values for the price and quality of the outside good, p_0 and v_0 , the price of good $i = 1 \dots n$, is recursively determined from

$$p_i = p_{i-1} + \theta_i(v_i - v_{i-1})$$

as implied by (1). Substituting the solutions for θ_i yields the reduced form collusive pricing equations:

$$p_i = p_0 + g^{-1} \left(\frac{c_1 - p_0}{v_1 - v_0} \right) (v_1 - v_0) + \sum_{j=2}^i g^{-1} \left(\frac{c_j - c_{j-1}}{v_j - v_{j-1}} \right) (v_j - v_{j-1}) \quad (4)$$

It now remains to check whether $\theta_1 < \theta_2 < \cdots < \theta_n < \bar{\theta}$, and whether $\underline{\theta} \leq \theta_1$, as was assumed. From the solution for θ_i and the fact that $g^{-1}(x)$ is monotonically increasing,

it follows that $\theta_i < \theta_{i+1}$ for $i = 1 \dots n - 1$ if $(c_i - c_{i-1})/(v_i - v_{i-1}) < (c_{i+1} - c_i)/(v_{i+1} - v_i)$ which 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 $\theta_n < \bar{\theta}$ if $(c_n - c_{n-1})/(v_n - v_{n-1}) < \bar{\theta}$. Finally, it can be verified that $\underline{\theta} < \theta_1$, i.e. not all consumers are served in equilibrium, if $\underline{\theta} - 1/f(\underline{\theta}) < (c_1 - p_0)/(v_1 - v_0)$.

4 Comparative statics

The tests for the presence of monopoly power are based on the comparative statics of the reduced form pricing equations (4) in cost and quality. The comparative statics under monopoly power are likely to be distinct from the comparative statics under more competitive regimes. More specifically, for the vertical differentiation model I show that this is true for several frequently used distribution functions of the taste parameter θ .

Using the reduced form pricing equation (4) the following comparative statics can be easily shown:

$$\frac{\partial p_i}{\partial c_k} = \frac{1}{g'(\theta_k)} - \frac{1}{g'(\theta_{k+1})}, \quad \frac{\partial p_i}{\partial v_k} = -\frac{g(\theta_k) - g'(\theta_k)\theta_k}{g'(\theta_k)} + \frac{g(\theta_{k+1}) - g'(\theta_{k+1})\theta_{k+1}}{g'(\theta_{k+1})}, \quad k = 1 \dots i-1$$

$$\frac{\partial p_i}{\partial c_i} = \frac{1}{g'(\theta_i)}, \quad \frac{\partial p_i}{\partial v_i} = -\frac{g(\theta_i) - g'(\theta_i)\theta_i}{g'(\theta_i)}$$

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

These comparative statics can be used to calculate the total effect of quality v_k on price p_i

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

The comparative statics yield a strong prediction and a weak prediction. These predictions can be used to test for the presence of monopoly power.

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

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

The strong prediction of monopoly power follows straightforward from the comparative statics. The weak prediction follows from the fact that $g'(\theta_k) = g'(\theta_{k+1})$ and $g(\theta_k) - g'(\theta_k)\theta_k = g(\theta_{k+1}) - g'(\theta_{k+1})\theta_{k+1}$ if $g''(x) = 0$. Notice that the weak prediction applies to several frequently used distributions, including the uniform, the Pareto and the exponential. This is illustrated by the following more general distribution function of the taste parameter θ , $F_\mu(x)$, which nests the above three special cases:

$$F_\mu(x) \equiv 1 - \left(1 - \mu \frac{x - \underline{\theta}}{\bar{\theta} - \underline{\theta}}\right)^{1/\mu}, \quad (5)$$

with $\theta \in [\underline{\theta}, \underline{\theta} + (\bar{\theta} - \underline{\theta})/\mu]$ if $\mu > 0$, and $\theta \in [\underline{\theta}, \infty]$ if $\mu \leq 0$.⁵ The uniform distribution obtains if $\mu = 1$; the exponential obtains if $\mu = 0$; the Pareto obtains if $\mu = -\bar{\theta} = -1/(1 + \lambda)$ and $\underline{\theta} = 0$. The reduced form pricing equation if $F(x) = F_\mu(x)$ is:

$$p_i = p_0 + \frac{1}{1 + \mu} \left(c(v_i) - p_0 + (\bar{\theta} - \underline{\theta} + \mu \underline{\theta})(v_i - v_0) \right) \quad (6)$$

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

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 . 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 competitive conduct 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 the marginal cost equations of perfect competition. In the more

⁵Notice a slightly different notation for the upperbound. It does not necessarily coincide with $\bar{\theta}$, as it was denoted before.

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 θ nevertheless all yield the following prediction of Bertrand-Nash equilibrium, in strong contrast with the predictions of monopoly power.⁶

Prediction of Bertrand-Nash equilibrium: The price of product i may depend on all qualities $v_1 \cdots v_n$, even if $g''(x) = 0$. Furthermore, the qualities $v_{i+1} \cdots v_n$ have a positive impact on p_i , whereas the qualities $v_1 \cdots v_{i-1}$ 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.⁷ 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. However, 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:

$$h(p_i) = \beta_{i,1}v_1 + \cdots + \beta_{i,i-1}v_{i-1} + v_i + \alpha_{i,i+1}v_{i+1} + \cdots + \alpha_{i,n}v_n + \epsilon_i, \quad (7)$$

⁶The calculations of the given examples are straightforward, and available on request.

⁷Formally, 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 ϵ_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

$$v_i = x_i\gamma, \tag{8}$$

where γ 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 $\alpha_{i,j} = 0$. If in addition the weak prediction of monopoly power holds, then all $\alpha_{i,j} = \beta_{i,j} = 0$, so that $h(p_i) = v_i + \epsilon_i = x_i\gamma + \epsilon_i$, which is just the popular *hedonic* specification.⁸ 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 $\alpha_{i,j} > 0$, whereas the sign of $\beta_{i,j}$ is ambiguous.

Unfortunately, to estimate (7) 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 $\alpha_{i,j}$ and $\beta_{i,j}$). 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 $\alpha_{i,j}$ and $\beta_{i,j}$ 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 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

⁸The 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 $\ln(p_i) = v_i + \epsilon_i$ is the monopoly solution if the distribution function $F_\mu(x)$ given by (5) holds, and the marginal cost function is given by $c(v_i) = (1 + \mu)(\exp v_i - p_0) + p_0 - (\bar{\theta} - \underline{\theta} + \mu\underline{\theta})(v_i - v_0)$, as may be easily verified from (6). This marginal cost function is increasing for $v_i > \ln(\bar{\theta} - \underline{\theta} + \mu\underline{\theta}) / (1 + \mu)$, and convex, as required.

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 $\alpha_{i,j}$ and $\beta_{i,j}$ in (7). More specifically, I propose to estimate the following alternative regression models to test for the presence of monopoly power.

Regression 1:

$$\ln(p_i) = \beta v_{i-1} + v_i + \alpha v_{i+1} + \epsilon_i$$

Regression 2:

$$\ln(p_i) = \beta_2 v_{i-2} + \beta_1 v_{i-1} + v_i + \alpha_1 v_{i+1} + \alpha_2 v_{i+2} + \epsilon_i$$

Regression 3:

$$\ln(p_i) = \beta^2 v_{i-2} + \beta v_{i-1} + v_i + \alpha v_{i+1} + \alpha^2 v_{i+2} + \epsilon_i$$

Regression 4:

$$\ln(p_i) = \beta^{i-1} v_1 + \beta^{i-2} v_2 + \dots + \beta v_{i-1} + v_i + \alpha v_{i+1} + \dots + \alpha^{n-i-1} v_{n-1} + \alpha^{n-i} v_n + \epsilon_i$$

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. $\ln(p_i) = v_i + \epsilon_i$. I also experimented with specifications in which $h(p_i) = \sqrt{p_i}$, but this did not affect the empirical results.

The structure imposed on the parameters $\alpha_{i,j}$ and $\beta_{i,j}$ is based on the intuition that *if* the presence of monopoly power is rejected, i.e. *if* $\alpha_{i,j}$ or $\beta_{i,j}$ 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 θ . The first regression model imposes the most restrictive structure: it allows product i 's price to be a function 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 (8), regressions 1, 2, and 3 can be easily estimated using some nonlinear least squares estimator. To facilitate estimation of regression 4 I apply a transformation similar to the Koyck transformation. Note first that for $i = 1 \cdots n - 1$

$$\ln(p_i) - \alpha \ln(p_{i+1}) = (1 - \alpha\beta)(\beta^{i-1}v_1 + \beta^{i-2}v_2 + \cdots + \beta v_{i-1} + v_i) + \epsilon_i - \alpha\epsilon_{i+1}.$$

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

$$(\ln(p_i) - \alpha \ln(p_{i+1})) - \beta(\ln(p_{i-1}) - \alpha \ln(p_i)) = (1 - \alpha\beta)v_i + \epsilon_i - \alpha\epsilon_{i+1} - \beta(\epsilon_{i-1} - \alpha\epsilon_i),$$

or

$$(1 + \alpha\beta)\ln(p_i) = (1 - \alpha\beta)v_i + \beta \ln(p_{i-1}) + \alpha \ln(p_{i+1}) + \epsilon_i(1 + \alpha\beta) - \beta\epsilon_{i-1} - \alpha\epsilon_{i+1}.$$

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

$$\ln(p_1) = (1 - \alpha\beta)v_1 + \alpha \ln(p_2) + \epsilon_1 - \alpha\epsilon_2$$

$$\ln(p_n) = (1 - \alpha\beta)v_n + \beta \ln(p_{n-1}) + \epsilon_n - \beta\epsilon_{n-1}.$$

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

$$(1 + \alpha\beta)(1 - l_i - h_i)\ln(p_i) = (1 - \alpha\beta)v_i + \beta(1 - l_i)\ln(p_{i-1}) + \alpha(1 - h_i)\ln(p_{i+1}) + \epsilon_i(1 + \alpha\beta) - \beta(1 - l_i)\epsilon_{i-1} - \alpha(1 - h_i)\epsilon_{i+1},$$

for $i = 1 \cdots n$. 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 by $x_i\gamma$. 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 $\alpha_{ij} = \beta_{ij} = 0$ in (7) 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 α_{ij} and β_{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 apply the proposed tests for monopoly power: the market for spreadsheets in the US (1986-1991) and the market for ‘engine variants’ in the 1990 French car market.⁹ The first sample allows to test the hypothesis of monopoly power across spreadsheet programs at a given time period. The second sample allows to test the hypothesis of monopoly power across the engine variants of the same given car model.

The first sample covers 6 years of the US spreadsheet market, with about 15 spreadsheet programs per year. This yields a panel of 91 spreadsheet observations for the period 1986-1991. The following variables are used here.¹⁰ 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 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

⁹The data on spreadsheets were provided by Neil Gandal. The data on the French car market, including the data on the extra option equipment, were collected from two sources: *Automobil Revue* and *l’Argus de l’Automobile et des Locomotions*.

¹⁰See Gandal (1994) for a more detailed discussion of these data.

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 (7) and (8), assuming $h(p_i) = \ln(p_i)$ and restricting $\alpha_{i,j} = \beta_{i,j} = 0$. Recall that this is just a simple hedonic regression, which holds under the null hypothesis of monopoly power. The included variables in this regression are selected from a larger set of variables, based on their significant contribution to the regression.¹¹ 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. 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, diesel and

¹¹The 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.

cylinder volume. 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 these variables Table 2 presents estimates of γ in (7) and (8), again assuming $h(p_i) = p_i$ and restricting $\alpha_{i,j} = \beta_{i,j} = 0$. These variables are selected from a 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).¹² 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.¹³ The estimates of the parameters α and β (and α_i and β_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 α and β are significantly different from zero, with the exception of some of the estimates for regression 2. All significant estimates of α are positive; all significant estimates of β are negative. The insignificant estimates in regression 2 may be due to the little structure imposed in this regression.

¹²The 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.

¹³In 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.

This is suggested by the significant estimate of α and β 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 α and β are usually not significant. Furthermore, the magnitude of the estimates of α and β is much smaller in the market for engine variants (Table 4) than in the market for spreadsheets (Table 3).¹⁴

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 α (positive) and β (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. This large number probably makes 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 memorandum on the 1966 American Ford Galaxie sedan, stating that the wholesale price minus accounting cost is much higher on the high quality engine variants than on the low quality variants, 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

¹⁴Some care had to be taken to allow for a reasonable comparison of the magnitudes of α and β . 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 $\ln(\text{PRICE})$ 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 .

present. For policy purposes one may view then the tests as one extra piece of possible evidence for the presence of monopoly power.

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 could 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 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 accessability', 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. If this assumption is not easy to justify, the proposed tests may again need modification.

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