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Distinguishing the Source of Market Power: An Application to Cigarette Manufacturing

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Abstract

We compare nonparametric and nonstructural market power tests using data from the cigarette manufacturing industry. Tests are implemented to examine both monopoly and monopsony power exertion by cigarette manufacturers. Results indicate that market power in the tobacco industry, previously attributed to monopoly power exertion, should at least in part be attributed to monopsony market power in the upstream tobacco market.

Keywords: market power, nonparametric, nonstructural, monopsony, monopoly, cigarette manufacturing

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DISTINGUISHING THE SOURCE OF MARKET POWER: AN APPLICATION TO CIGARETTE MANUFACTURING

Introduction

Nonparametric and nonstructural tests of market power offer alternatives to parametric tests of market power in that they circumvent the issue of functional form choice for behavioral equations (Ashenfelter and Sullivan 1987, Hall 1988, Varian 1984). Both approaches rely on price and quantity data for inputs and output but do not rely on a specific technology specification. Additionally, data requirements are less for nonparametric and nonstructural market power tests than for parametric market power tests because supply or demand relationships in the opposing market need not be specified.

Nonstructural market power tests are computed from actual changes in costs rather than from assuming profit maximization and estimating the slope of the demand schedule as do most parametric market power studies (Hall). Recent studies (Hall; Domowitz, Hubbard and Peterson (1988); Hyde and Perloff (1994); and Roeger (1995)) develop nonstructural market power tests that compute a monopoly markup or monopsony markdown term and technology component based on Solow residuals. A simple regression generates a testable hypothesis of market power. Thus, nonstructural techniques offer a compromise between traditional econometric estimation of market power which must assume a specific underlying technology and nonparametric methods which are deterministic in nature. Although nonstructural market power tests give a testable hypothesis regarding market power, they do have some inherent problems. Nonstructural market power tests rely on the assumption of constant returns to scale (CRS) and thus test the joint hypothesis of competition and CRS (Hall, Roeger). More importantly, previous applications have used identical approaches to test for monopoly or monopsony market power (Hall, Hyde and Perloff). Thus, the question remains whether this approach can be useful in distinguishing monopoly or monopsony power as the underlying source of market power exertion.

The primal profit-maximization approach used to develop nonparametric market power tests provides dissimilar empirical equations for monopoly power and monopsony power. In addition, nonparametric market power tests do not make the assumption of CRS. However, previously developed nonparametric market power tests exhibit methodological weaknesses. Some studies have assumed stable cost and demand conditions and ignored factors that may bias market power measurements, such as technical change (Ashenfelter and Sullivan). However, Love and Shumway (1994) have included measures of technical change in their implementation of a monopsony market power test. An additional criticism of previous nonparametric market power tests is that they do not incorporate stochastic variation, and as such, have no probabilistic interpretation. In effect, nonparametric deterministic tests are based on an exhaustive search for violations of the underlying hypothesis. If a violation is detected, the underlying hypothesis is rejected. Ashenfelter and Sullivan mention this as a criticism of nonparametric tests in general, as does Varian (1984, 1985). However, Varian (1984, 1985) has developed nonparametric statistical tests based on measurement error or goodness of fit that provide a basis for evaluating the seriousness of optimization violations.

In this paper, in addition to developing nonstructural monopsony market power tests and nonparametric monopoly market power tests, we also implement nonstructural and nonparametric market power tests for monopoly and monopsony market power using cigarette manufacturing industry data. Conveniently, each test requires the same data whether testing for monopoly market power or monopsony market power. This allows an interesting comparison between nonstructural and nonparametric market power tests. We compare Hall's and Roeger's test for monopoly market power and the analogous monopsony market power test to three nonparametric tests: a revised

Ashenfelter and Sullivan test, Love and Shumway's linear programming test, and a new nonparametric quadratic programming statistical test. The three nonparametric tests are developed for both the monopoly and monopsony cases. All follow the revealed preference approach of Ashenfelter and Sullivan. We extend Ashenfelter and Sullivan's approach by incorporating cost data and omitting shifts in the opposing market. Love and Shumway's nonparametric monopsony power test is modified for the monopoly case. A nonparametric statistical test is developed for both the monopoly and monopsony cases that includes the possibility of stochastic errors in optimization and technical change.

The U.S. cigarette manufacturing industry provides an appealing market for this analysis since Ashenfelter and Sullivan focus on this industry and both Hall and Roeger include results from the tobacco industry. Previous studies have considered monopoly power exertion by tobacco processors, but their potential monopsony power in procuring tobacco from domestic growers has received little attention (Ashenfelter and Sullivan, Hall, Roeger, Sullivan, Sumner).[1] We examine the relationship between cigarette manufacturers and wholesalers as well as the behavior of cigarette manufacturers in procuring domestic tobacco. While manufacturing data at the two-digit SIC level is often used to examine monopoly power in the industry (e.g., Roeger, Hall), we conduct our analysis using more specific four-digit SIC code data. We also incorporate costs of domestic and imported tobacco, labor, advertising, capital, and materials. Empirical results suggest that cigarette manufacturers exert monopsony power in addition to commonly assumed monopoly power.

[1]The only study which considers monopsony power by cigarette manufacturers that the authors are aware of is Hamilton. His study analyzes cigarette manufacturing data from the period 1924-1939 for joint oligopoly-oligopsony. His results suggest that oligopolistic cigarette pricing was practiced during this period by cigarette manufacturers, but that oligopsonistic coordination of leaf tobacco purchases was not present.

This paper is organized as follows. First, we present a brief discussion of potential market power in the cigarette manufacturing industry. Next we present Hall's and Roeger's nonstructural market power tests and develop the analogous tests for monopsony market power. Nonparametric tests, including Ashenfelter and Sullivan's test, a revised Ashenfelter and Sullivan test, Love and Shumway's test, and a new statistical test, are developed for both the monopoly and monopsony cases. We then implement these nonparametric and nonstructural tests to analyze cigarette manufacturers' potential monopoly and monopsony power exertion. Empirical results are followed by concluding remarks.

The Cigarette Manufacturing Industry

The cigarette manufacturing industry has long been touted as an example of an imperfectly competitive industry. Given the high level of concentration that exists in this industry, monopoly power exertion by cigarette manufacturers is certainly plausible. In 1992, the industry contained only eight firms with the four largest firms supplying ninety-three percent of cigarette production (Census of Manufacturers, special tabulation). However, concentration measures also support the possibility of cigarette manufacturers exerting monopsony power in procuring domestic tobacco. In 1995, U.S. tobacco growers produced 1,268 million pounds of tobacco, 933 million pounds of which was sold domestically for the production of cigarettes. While there are thousands of tobacco growers, each has access to a very limited number of buyers for the product. Tobacco is also a highly specialized crop, both in production and in use. As stated in Rogers and Sexton (p. 1143), "...the relevant markets for raw agricultural products will typically be narrower with respect to both product class and geography than the markets for the finished products they produce." The relatively inelastic supply of tobacco, due to the farm program supply restrictions, and high buyer concentration suggest the potential for monopsony market power exertion by cigarette manufacturers.

Several studies of the cigarette industry have examined monopoly power of cigarette manufacturers in the retail market (Sumner, Sullivan, Ashenfelter and Sullivan). Market power exertion has typically been measured by examining firms' responses to varying excise tax levels. Sumner discusses the possibility of upward biases on measurements of cigarette manufacturers' monopoly power exertion due to added market power exertion by wholesalers and retailers. However, he assumes that the large number of firms in these segments of the marketing chain leads to minimal monopoly power exertion. Sumner assumes that any distortion in pricing by cigarette manufacturers is passed through these two segments directly to consumers with little bias. Ashenfelter and Sullivan, Sullivan, and Sumner all maintain this assumption in using retail level price and quantity data in their analyses. Sumner rejects both competition and collusion and contends that the industry operates at some level of oligopoly. Ashenfelter and Sullivan, along with Sullivan, reject the perfect cartel case and argue instead that the industry exhibits at least a “moderate” level of competition.

Measuring Imperfect Competition

Market power is defined as deviation from marginal cost pricing. Such deviations may be in the form of monopoly power, where output price is greater than marginal cost (MC), or in the form of monopsony power, where input price is less than the value of marginal product (VMP). Nonstructural market power tests measure the relationship between price and marginal cost by comparing actual growth in the output/capital ratio with the expected growth given the rate of technical progress and growth in the labor/capital ratio (Hall). Differences between actual and expected growth are attributed to market power. Nonparametric market power tests employ a revealed preference approach founded on the weak axiom of profit maximization (WAPM). For consistency with competitive behavior, WAPM states that the observed input and output quantity choices at output price p and input prices r_m must yield profit at least as great as any other quantity set that could have been chosen (Varian, 1984). If a firm is exerting market power, it will be evidenced by the quantity choices made in each period.

The nonstructural and nonparametric market power tests presented here are developed from firm *i*'s profit maximization problem:

$$\textbf{(1)} \qquad \max_{y_i,\, x_{mi}} \pi_i = p y_i - \sum_{m=1}^{n} r_m x_{mi} \text{ s.t. } F_i(\mathbf{x}) \geq y_i \,,$$

where p is output price, y_i is firm *i*'s output, x_{mi} is quantity of variable input m demanded by firm *i*, r_m is the price of input m, $\mathbf{x}$ is the vector of variable inputs, and $F_i(\mathbf{x})$ is firm *i*'s production function.

Nonstructural Tests

Nonstructural tests do not require functional form specification of the firm's technology. They have an added advantage over nonparametric tests of including a statistically testable hypothesis concerning market power exertion, but they require the additional assumption of CRS. Consequently, such tests are a joint test of competition and CRS (Hall).[2] Hall's and Domowitz, Hubbard, and Petersen's nonstructural monopoly market power tests use a primal approach based on the Solow residual. Roeger extends their work by incorporating a dual measure of the Solow residual.

Primal Approach

Following Domowitz, Hubbard and Petersen's notation, we develop their monopoly market power test for a firm with one output y and three inputs: capital, x_1; an aggregate of variable inputs other than domestic tobacco, x_2; and domestic tobacco, x_3. Their test also assumes autonomous

[2]The nonstructural tests presented require time-series data; however, we omit the time subscripts for notational simplicity.

Hicks-neutral technical progress. Under these assumptions we can represent the industry's production function as:

(2) $$y = A\, e^{\gamma}\, f(x_1, x_2, x_3)$$

where γ is the rate of Hicks-neutral technical progress and A represents a productivity shock. Assuming CRS technology and competitive behavior in all input and output markets, the Solow residual (Solow) for this technology is represented by:

(3) $$\dot{y}/y - \alpha_{x2}\dot{x}_2/x_2 - \alpha_{x3}\dot{x}_3/x_3 = \dot{A}/A + \dot{\gamma}$$

where output and inputs are normalized by input x_1 and hence $y/x_1 = y$, $x_2/x_1 = x_2$ and $x_3/x_1 = x_3$ and where $\alpha_{xi} = f_{xi}x_i/y = r_i x_i/py,\ i = 1,\ 2,\ 3$ (See Appendix A).

The Solow residual assumes that output is valued at its marginal cost. Hall argues that in the presence of monopoly market power, firms can sell incremental output for more than what they pay for incremental inputs. Hence, the firm's profits will rise in excess of input cost. In this case the Solow residual must be modified. If the firm's market price exceeds its marginal cost, then the variable cost share α_v^* is equal to $(P/MC)(\alpha_{x2}+\alpha_{x3})$. Hence the Solow residual becomes

(4) $$\dot{y}/y - \alpha_{x2}\dot{x}_2/x_2 - \alpha_{x3}\dot{x}_3/x_3 = \dot{A}/A + \dot{\gamma} + \beta\dot{y}/y$$

where β is the monopoly Lerner index ($\beta = \frac{P - MC}{P}$), $\dot{\gamma}$ is the rate of Hicks neutral technical change and $\dot{A}/A$ is the instantaneous percentage change in productivity shock.

Equation (4) gives Domowitz, Hubbard and Petersen's estimating equation for monopoly market power exertion and is similar to Hall's. Domowitz, Hubbard and Petersen's test yields a testable hypothesis regarding β^{mp} where positive values of β^{mp} indicate monopoly market power exertion. The primary difference between the two tests is that Hall does not directly estimate the monopoly Lerner index, but instead estimates the monopoly markup's reciprocal $\gamma_H = 1/\mu^{mp}$ where μ^{mp} is related to the monopoly Lerner index as $\beta^{mp}=(1-1/\mu^{mp})$. Hence the monopoly Lerner index is recovered by $\beta^{mp}=1-\gamma_H$. If $\mu^{mp} = 1$, industry pricing is perfectly competitive. If $\mu^{mp} > 1$, price exceeds marginal cost and monopoly market power is being exerted.

In equation (4), $\dot{A}/A$ represents an observable error term since input use is simultaneously determined by the firm with output. $\dot{y}/y$ is likely correlated with the productivity shock $\dot{A}/A$. To obtain a consistent estimate of β, instrumental variable estimation must be used and an instrumental variable must be found that is correlated with movements in output but is uncorrelated with the productivity shock. Using Hall's approach, market power estimation depends critically on finding an appropriate instrumental variable. Hall's tests rest on the simple proposition that,

> to the extent that the firm is noncompetitive, its measured productivity will be associated with its rate of growth of labor input over fluctuations associated with an exogenous instrument. When productivity rises along with employment in response to an outside force, it is a sign that the firm is not competitive. (p. 928)

The instrumental variable must be positively correlated with output, but neither be caused by productivity fluctuations nor result from productivity fluctuations. Demand shock variables are ideal candidates for instruments for identifying monopoly market power exertion while supply shock variables are good candidates for estimating monopsony market power exertion. However, finding appropriate instrumental variables for a specific industry can be problematic and estimation results are sensitive to instrument choice (Roeger).

We extend Hall's and Domowitz, Hubbard and Petersen's nonparametric monopoly market power test to test for monopsony market power exertion in a single input market. The principal difference from the monopoly test is that the right-hand side explanatory variable is domestic tobacco input cost share multiplied by an instantaneous percent growth in domestic tobacco input use whereas in models of monopoly market power, the right-hand side explanatory variable is instantaneous output growth. The Solow residual assumes that all inputs are valued at their respective marginal value products. With monopsony market power, when a firm expands output it will be able to purchase the input in which it has market power (x_3) at a proportionately lower price than its internal value to the firm. As in the monopoly case, the firm's profits will rise in excess of input cost and the Solow residual must be modified to reflect this possibility. If the firm's marginal value product of an input (x_3) exceeds its market price, then its cost share α_{x3}^* must equal α_{x3} (VMP/r_3). Hence the Solow residual becomes

$$\dot{y}/y - \alpha_{x2}\dot{x}_2/x_2 - \alpha_{x3}\dot{x}_3/x_3 = \dot{A}/A + \dot{\gamma} + \beta\alpha_{x3}\dot{x}_3/x_3 \tag{5}$$

where β is the monopsony Lerner index $\left(\beta = \frac{VMP_{x3} - r_3}{r_3}\right)$, and other variables are defined as before. Positive values of β indicates monopsony power exertion while β=0 indicates perfectly competitive behavior. As previously discussed, implementation of the test requires instrumental variable estimation since $\alpha_{x3}\,\dot{x}_3/x_3$ is likely correlated with the productivity shock $\dot{A}/A$.

Primal-Dual Approach

Hall's and Domowitz, Hubbard, and Petersens' tests are based on a primal formulation of the Solow residual. Roeger extends this nonstructural method by including a dual measure of the Solow residual, which does away with the need for instrumental variable estimation. Roeger's nonstructural equation for monopoly power exertion is based on the difference between primal and dual Solow residuals.

Following Roeger, we first develop the dual Solow residual under perfect competition and then later relax this assumption by allowing market power exertion. A general cost function C (·) for a firm operating under perfect competition and constant returns-to-scale is:

$$C(r_1,\ r_2,\ r_3,\ y,\ A,\ \gamma) = \frac{G(r_1,\ r_2,\ r_3) - y}{Ae^{\gamma}} \tag{6}$$

where G(·) is the unit cost function and is homogeneous of degree 1 and all other variables are defined as above.

The dual Solow residual can be obtained in several steps. First, assuming perfect competition in the output market, the price dependent supply is given by:

$$p = \partial\, C(\cdot)/\partial y = G(r_1, r_2, r_3)/Ae^{\gamma}\ . \tag{7}$$

Now, totally differentiating (7) with respect to time and dividing by P or $G(\cdot)/Ae^{\gamma}$ as appropriate gives:

$$\dot{p}/p = \partial G/\partial r_1\ \dot{r}_1/G + \partial G/\partial r_2\ \dot{r}_2/G + \partial G/\partial r_3\ \dot{r}_3/G - \dot{A}/A - \dot{\gamma} \tag{8}$$

From Shepard's Lemma $\partial C/\partial r_i = \partial G/\partial_{RI} \cdot Q/Ae^{\gamma} = x_i$, so $\partial G/\partial_{RI} = x_i\ Ae^{\gamma}/Q$. Substituting this result into (8) and recognizing $Ae^{\gamma}/QG = 1/C$ gives

$$\dot{p}/p = r_1x_1/C\ \dot{r}_1/r_1 + r_2x_2/C\ \dot{r}_2/r_2 + r_3x_3/C\ \dot{r}_3/r_3 - \dot{A}/A - \dot{\gamma}. \tag{9}$$

Assuming constant returns to scale technology and competitive input markets, the input cost share $r_ix_i/C = \alpha_{xi}$ and $\alpha_{xi} = 1 - \alpha_{x2} - \alpha_{x3}$, using these definitions in (9) gives:

$$\dot{\mathit{p}}/\mathit{p} = \alpha_{x2}\dot{\mathit{r}}_2/\mathit{r}_2 + \alpha_{x3}\dot{\mathit{r}}_3/\mathit{r}_3 - \dot{A}/A - \dot{\gamma}. \tag{10}$$

where $\mathit{p} = p/r_1$, $\mathit{r}_2 = r_2/r_1$ and $\mathit{r}_3 = r_3/r_1$.

The price-based Solow residual in equation (10) assumes that output is valued at its marginal cost. However, if firms are exerting monopoly market power, output will be sold for a price greater than marginal cost. To include this possibility in the Solow residual, let β=(p-MC)/p be the monopoly Lerner index. It follows that MC = p(1-β). Substituting this expression into (10) gives

(11) $$(1-\beta)\dot{p}/p = \alpha_{x2}\dot{r}_2/r_2 + \alpha_{x3}\dot{r}_3/r_3 - \dot{A}/A - \dot{\gamma}.$$

Rearranging in terms of the price-based Solow residual gives

(12) $$\alpha_{x2}\dot{r}_2/r_2 + \alpha_{x3}\dot{r}_3/r_3 - \dot{p}/p = \beta\dot{p}/p + \dot{A}/A + \dot{\gamma}.$$

Denoting the left-hand side of (12) SRP and the left-hand side of (4) SR and substituting for $\dot{A}/A$ in (4) gives the estimating equation for β:

(13) $SR - SRP = \beta(\dot{y}/y + \dot{p}/p)$.

Following Roeger, under the maintained assumptions that factors can be instantaneously adjusted and no measurement errors exist in the data, the difference between the primal and dual Solow residuals should be equal to zero in all periods if there is no monopoly market power exertion. In reality, there are measurement errors associated with data collection and all inputs are not adjusted instantaneously. As a result, an error term must be appended to equation (13) to form the estimating equation. However, unlike Hall's test, the error term associated with equation (13) should not generally be correlated with the explanatory variable since it represents errors in measurement and not systematic errors in productivity growth associated with input use. Indeed any systematic errors in productivity growth $\dot{A}/A$ should exactly offset one another when the dependent variable is measured as the difference between the primal and dual Solow residuals. As a result, the monopoly Lerner index can be estimated from equation (13) with an additive error term using ordinary least square regressions. Roeger does note conditions under which error terms associated with equation (13) may exhibit serial correlations and/or heteroscedasticity.

A primal-dual nonstructural test of monopsony power can be developed in an analogous manner. The price-based Solow residual contained in equation (10) assumes that all inputs are valued at their respective marginal value products, i.e., each is paid its respective factor cost share. If firms are exerting monopsony market power in the domestic tobacco market, firms pay a lower price for domestic tobacco than the internal value of domestic tobacco to the firm. Again, the Solow residual must be modified to include this possibility. Let $\beta = (VMP_{x3} - r_3)/r_3$ be the monopsony Lerner index, then $VMP_{x3} = (\beta + 1)r_3$. Substituting this expression into equation (10) gives

$$\dot{p}/p = \alpha_{x2}\dot{r}_2/r_2 + (\beta + 1)\,\alpha_{x3}\dot{r}_3/r_3 - \dot{A}/A - \dot{\gamma}. \tag{14}$$

which can be rearranged in terms of the price-based Solow residuals:

$$\alpha_{x2}\dot{r}_2/r_2 + \alpha_{x3}\dot{r}_3/r_3 - \dot{p}/p = -\beta\alpha_{x3}\dot{r}_3/r_3 + \dot{A}/A + \dot{\gamma}. \tag{15}$$

The estimating equation for the monopsony power test is developed from difference of the primal and dual Solow residuals which incorporate the possibility of monopsony power exertion. Denoting the left-hand side of (15) SRP and the left-hand side of (5) SR and substituting for $\dot{A}/A$ in (5) gives the estimating equation for β in the case of potential monopsony power exertion:

$$SR - SRP = \beta\alpha_{x3}(\dot{x}_3/x_3 + \dot{r}_3/r_3). \tag{16}$$

With market power in the case of domestic tobacco, this differential is equal to the monopsony Lerner index times the domestic tobacco cost share times the sum of the instantaneous percent change in domestic tobacco use and the instantaneous percentage change in domestic tobacco price.

Nonparametric Tests

Nonparametric tests offer an advantage over parametric tests because results are independent of functional form (Varian, 1984, 1985, 1990). Initial market power studies in this area, such as Ashenfelter and Sullivan, extend the axioms of revealed preference to include the pricing advantage that market power can give. Such tests exploit the idea that firms with market power will restrict quantities in order to maximize profits and that, at observed prices, there is no other quantity choice that will yield a higher profit. For the perfectly competitive firm, the discrete profit-maximizing condition is

(17) $$\Delta\pi_i = p\Delta y_i - \sum_{m=1}^{n} r_m \Delta x_{mi} \leq 0 \ .$$

Here we assume that prices are exogenous since the firm cannot influence prices through input or output quantity choice. However, a firm with monopoly power can influence output price p by its choice of output level y_i. In this case, the first-order condition becomes

(18) $$\Delta\pi_i = p\Delta y_i + y_i \Delta p - \sum_{m=1}^{n} r_m \Delta x_{mi} \leq 0 \ .$$

Nonparametric methods typically parameterize the second left-hand-side term of the inequality, commonly known as the monopoly markup term, by multiplying it by a monopoly power index like β^{mp}. In the perfectly competitive case, the firm cannot influence output prices so $\beta^{mp}=0$. If the firm is exerting monopoly power, p is no longer exogenous since the firm's choice of y_i can influence output price. The degree of this influence is measured by β^{mp}.

The revealed preference approach can also be applied to the monopsony case where we consider potential market power in an input market, x_n. The monopsonistic firm's profit-maximizing condition in discrete terms is

(19) $$\Delta\pi_i = p\Delta y_i - \sum_{k=1}^{n-1} r_k \Delta x_{ki} - r_n \Delta x_{ni} - x_{ni} \Delta r_n \leq 0 \ ,$$

where x_{ki} is the quantity of variable input x_k purchased by the *i*th firm and x_{ni} is the amount of x_n purchased by the *i*th firm. Input price r_n is no longer exogenous since the quantity of x_n purchased by firm i influences price. The monopsony markdown term is the fourth left-hand-side term.

Analogous to the monopoly case, it is parameterized with monopsony power index β^{ms}. In perfect competition, the firm cannot influence input prices so $\beta^{ms}=0$.

<u>Ashenfelter and Sullivan</u>

Ashenfelter and Sullivan's nonparametric monopoly power test is based on the primal profit maximizing condition in equation (19). They use average retail prices and average per capita consumption by state in evaluating the reaction of cigarette producers to changes in marginal cost via changes in excise taxes. The market power index, β^{mp}, is attached to the monopoly markup term. The test assumes that costs other than the excise tax are stable so that changes in the excise tax (et) are equivalent to changes in marginal cost. This assumption allows measures of cost other than excise tax to be omitted from the test and greatly lessens the data requirement. A stable demand function is also assumed, resulting in an upper bound estimate of monopoly power. In application, the test is

$$\beta^{mp} \leq \frac{-(p^t - et^s)(y_i^t - y_i^s)}{(p^t - p^s)\, y_i^s} \quad \forall\ s \neq t \ \text{ when } |t-s| \leq 2 \,, \tag{20}$$

where et^s represents the excise tax in effect during time period s.[3] Market power exertion, β^{mp}, can only be rejected in favor of more competitive structures. This measure is then used to obtain a lower bound for n_t, the "numbers equivalent of Cournot firms", where $n_t \geq 1/\beta^{mp}$ and represents the smallest number of Cournot firms that the industry can support (Sullivan). Ashenfelter and Sullivan's test is based on the maintained hypothesis that supply and demand functions do not shift. In reality, both supply and demand can shift through time. To minimize measurement error in the tax data and the

[3]Ashenfelter and Sullivan's assumption of an upward sloping cost function, $C(y_j)$, maintains the integrity of the inequality when input costs are omitted from the test. If we assume $y_i^t < y_i^s$ so that $C(y_i^t) < C(y_i^s)$, the upper bound for β^{mp} is higher when input costs are included.

possibility of false rejections of market power exertion due to supply or demand shifts,they only apply their test to pairs of points which are no more than two years apart.

Ashenfelter and Sullivan's pioneering nonparametric market power test suffers from two admitted weaknesses: (1) the assumption of stable cost functions and (2) the assumption of a stable demand curve in the opposing market. While Ashenfelter and Sullivan attempt to limit these problems by considering only pairs of points from the same region and close in time, a more precise remedy can be implemented. It is reasonable to assume that the cost structure of a firm or industry may change over time. These changes can be accounted for by including measures of cost for each period. It is also reasonable to assume that substitute prices, income or consumer preferences and thus market demand may shift over time. When comparisons are only made between "near" data points, valuable information from comparisons where shifts did not occur may be lost. Since a demand shift unmatched by a shift in supply will cause output price and quantity to move in the same direction between observations, deleting comparisons where Δy_i has the same sign as Δp can also reduce the possibility of false rejections (Love and Shumway). Such movements are clearly not attributable to market power exertion. Likewise, in the monopsony case, input prices and quantities may move in opposite directions between observations due to shifts in input supply unmatched by shifts in input demand. In developing the analogous test for monopsony power, we delete comparisons between time periods when Δr_n does not have the same sign as Δx_{ni}.

Ashenfelter and Sullivan also point out that their model is quite simple and omits potentially important factors, such as advertising. We further enhance Ashenfelter and Sullivan's test by incorporating the cost of advertising. The revised monopoly power test is

(21)
$$\beta^{mp} \le \frac{-p^t(y^t - y^s) + \sum_{m=1}^{n} r_m (x_{mi}^t - x_{mi}^s)}{y^s(p^t - p^s)}$$

$$\forall\ s \ne t \text{ except when } (y^t - y^s) \overset{s}{=} (p^t - p^s)\ ,$$

where $\overset{s}{=}$ means "same sign as". The analogous monopsony test, based on equation (19), is

(22)
$$\beta^{ms} \le \frac{(p^t)(y^t - y^s) - \sum_{m=1}^{n} r_m^t (x_{mi}^t - x_{mi}^s)}{(r_n^t - r_n^s)\, x_{ni}^s}$$

$$\forall\ t \ne s \text{ except when } r_n^t - r_n^s \overset{s}{\ne} x_{ni}^t - x_{ni}^s\ ,$$

where $\overset{s}{\ne}$ means "not the same sign as".

Love and Shumway

More recently, nonparametric market power tests have incorporated measures of other variables which, if not accounted for, could distort market power measurements. Love and Shumway's inclusion of technical change measures in their deterministic monopsony power test is based on previous tests for profit maximization under perfect competition by Chavas and Cox (1988, 1990, 1992) and Cox and Chavas. To incorporate technical change measures, consider the primal profit maximization problem presented in equation (1). $F_i(\mathbf{x}) \ge y_i$ can be redefined as $F_i(\mathbf{x}) \ge Y_i(y_i, \mathbf{A})$ where Y_i denotes "effective output" and $\mathbf{A}>0$ is a vector of technology indices. $F_i(\mathbf{x})$ is assumed to be strictly increasing and concave in **x,** and Y_i is assumed to be a strictly increasing function of y. Consider the indirect profit function derived from equation (1) when technical change measures are included:

$$(23) \qquad \Pi(p, r, \mathbf{A}) = \underset{y_i, x_{mi}}{\text{Max}} \{\pi_i = p y_i(Y_i, \mathbf{A}) - \sum_{m=1}^{n} r_m x_{mi} : F_i(\mathbf{x}) \geq Y_i(y_i, \mathbf{A})\} ,$$

where $y_i(Y_i, \mathbf{A})$ is the inverse function of $Y_i(y_i, \mathbf{A})$. Assume the firm chooses input and output quantities ($\mathbf{x}$, y_i) over T time periods where each time period is characterized by input prices r^t, output price p^t, and technology $\mathbf{A}^t$. It is possible to check the consistency of the decision set, $\Omega_i = \{\mathbf{x}^1, y_i^{\,1}; \mathbf{x}^2, y_i^{\,2}; \ldots \mathbf{x}^T, y_i^{\,T}\}$ with the profit maximization hypothesis while considering the degree of market power exertion.

Recall that the firm with monopsony power in an input market, x_n can influence input price r_n by its choice of input level x_{ni}, resulting in equation (19) as a profit-maximizing condition. It is implicitly assumed in our revealed preference discussion of (11) that $\Delta y_i = y^s - y^t$. If we assume instead that $\Delta y_i = y^t - y^s$, this inequality can now be rewritten as

$$(24) \qquad p^{\,t}\,[(y_i(Y_i^{\,t}, A^{\,t}) - (y_i(Y_i^{\,s}, A^{\,s}))] - \sum_{k=1}^{n} r_k^{\,t}(x_{ki}^{\,t} - x_{ki}^{\,s}) - m_i^{ts}(x_{ni}^{\,t} - x_{ni}^{\,s}) \geq 0 \quad ,$$

where $m_i^{ts} = r_n^{\,t}\eta_i^{ts}$. This equation simply restates WAPM in terms of the quantity choice at time t, i.e., at observed prices in time t, the observed quantity in time t yields at least as much profit as any choice observed in another time period. The price flexibility of the *i*th firm's perceived residual supply curve is represented by $\eta_i^{ts} = [(r_n^{\,t} - r_n^{\,s})/(x_{ni}^{\,t} - x_{ni}^{\,s})]\,(x_{ni}^{\,t}/r_n^{\,t})$, which can also be written as $\eta_i = (VMP_{ni} - r_n)/r_n$, where VMP_{ni} is the marginal value product of the nth input for the *i*th firm (Love and Shumway). Thus η_i^{ts} is a direct measurement of the monopsony Lerner index, β^{ms}. The monopsony market power estimate can be recovered as $\beta^{ms} = \eta_i^{ts} = m_i^{ts}/r_n^{\,t}$. If $\beta^{ms} = 0$, then firm *i* believes it cannot impact input price by adjusting quantity purchased. If $\beta^{ms} > 0$, then firm *i* perceives the residual supply curve it faces as upward sloping and that it is exerting market power in the input market by reducing purchases of x_{ni} below the competitive level. Equation (24) gives the necessary and sufficient conditions for the firm's decision set Ω_i to be consistent with profit maximization (See proposition 1 in Chavas and Cox, 1990).

Empirical implementation of the market power test requires an assumption about the form of technical change. Chavas and Cox (1990) provide a thorough presentation of choosing hypotheses about technical change which make the problem empirically tractable without imposing a parametric model of technology. We assume their output translating case that presumes Hicks-neutral technical change. Output translating technical change leaves the marginal rate of substitution between inputs unchanged and is simple to operationalize. Define $Y_i(y_i, \mathbf{A})=f_i(y_i, a^+, a^-)$ where a^+ denotes positive technical change and a^- denotes negative technical change. Assuming output translating technical change gives $\Delta y = y_i^t - a^{t+} + a^{t-} - y_i^s + a^{s+} - a^{s-}$.

The inequality in (24) involves variables which are not directly observable. Therefore, the market power test consists of finding whether values exist for a^+, a^-, and m_i^{ts} which satisfy the inequality. Since (24) is linear in the unobserved variables, we can define $\mathbf{z}$ as the vector of unobserved variables, i.e. a^+, a^-, and m_i^{ts}, and rewrite (24) as $\mathbf{d'z} \geq \mathbf{c}$ using appropriate definitions of the matrix $\mathbf{d}$ and vector $\mathbf{c}$ and where ' denotes the transpose (Cox and Chavas, 1990). The market power test can now be implemented as the linear programming problem:

$$\min_{z} \{\mathbf{b\ z}:\ \mathbf{d\ z} \geq \mathbf{c},\ \mathbf{z} \geq 0\}\ . \tag{25}$$

In practice, we again delete comparisons between time periods when Δr_n does not have the same sign as Δx_{ni}, i.e. supply shifts without corresponding demand shifts, and search over $s \neq t$.

The test is easily adapted to the monopoly power case. A firm with monopoly power influences output price p by its choice of output level y_i resulting in equation (18) as a profit-maximizing condition. We incorporate the possibility of technical change so that the equation becomes

$$(26) \qquad p^t[y_i(Y^t,\mathbf{A}^t) - (y_i(Y^s,\mathbf{A}^s)] - mp_i^{ts}(y_i^t - y_i^s) - \sum_{k=1}^{n} r_k^t(x_{ki}^t - x_{ki}^s) \geq 0 \ ,$$

where $mp_i^{ts} = \omega_i^{ts}p^t$, and other variables are defined as before. The price flexibility of the *i*th firm's perceived residual demand curve is denoted as $\omega_i^{ts} = [(p^t - p^s)/(y_i^t - y_i^s)](y_i^t/p^t)$. The term ω_i^{ts} can also be interpreted as the monopoly Lerner index since $\omega_i = [(p - MC_i)/p]$, where MC_i is marginal cost for the *i*th firm. Solutions for the monopoly Lerner index, β^{mp}, are recovered by $\beta^{mp} = mp_i^{ts}/p^t$. Again, we can determine if solutions for a^+, a^-, and mp_i^{ts} exist which satisfy the inequality in (26) by searching over $s \neq t$ and omitting comparisons between time periods when Δp has the same sign as Δy_i to adjust for demand shifts unmatched by supply shifts.

Unlike Ashenfelter and Sullivan, these deterministic tests compare all pairs of observations except those representing clear shifts in the opposing market's curve, hence making more complete use of available information. Nevertheless, the method is still subject to the standard criticism that nonparametric techniques do not admit stochastic variation. That is, profit maximization is rejected from a single violation without regard to the severity of the violation.

Nonparametric Statistical Test

In this section we develop a nonparametric approach that provides a probabilistic framework for assessing market power exertion. Following Love and Shumway, our test includes separate measures for market power exertion and technical change. The deterministic model yields infeasible solutions for periods in which observed market power is negative. Even if the true market power parameter is positive, observed market power can take negative values when firms do not perfectly execute market power strategies. Firms must base quantity choices on "perceived" residual supply curves which depend on imperfectly forecasted supply relations and on competitors' reactions which are also unknown. Errors in these forecasts or errors from other sources may result in imperfect market power exertion. In addition, observations may not be perfect measurements of behavior due to measurement error (Varian (1985), Lim and Shumway).

Stochastic variation can be incorporated into nonparametric market power tests through the Lerner index. Let β_i represent firm *i*'s intended market power exertion. Then the relationship between firm *i*'s observed market power parameter m_i^{ts} and its intended behavior β_i is

(27) $$\frac{m_i^{ts}}{r^t} = \beta_i + \varepsilon_i^{ts} \ ,$$

where ε_i^{ts} is a random error term assumed to be independently and identically distributed $N(0, \sigma_i^2)$. Since $(\varepsilon_i^{ts}/\sigma_i)^2 \sim \chi^2_1$, it follows that $\Sigma_i^V (\varepsilon_i^{ts} / \sigma_i)^2 \sim \chi^2_V$ where V is the number of time period comparisons excluding unmatched supply or demand shifts. Solving (27) for ε_i^{ts} and substituting, we obtain the test statistic:

(28) $$E = \sum_{v=1}^{V} (m_i^{ts}/r_n^t - \beta_i)^2/\sigma_i^2 \ .$$

Under H_0: $m_i^{ts}/r_n = \beta_i$, E is distributed as a chi-squared statistic with V degrees of freedom where V = $(t^2 - t) - z$, and z is the number of observations deleted because of unmatched supply or demand shifts. Generally σ_i^2 is not known, but

(29) $$R = \sum_{v=1}^{V} (m_i^{ts}/r_n^t - \beta_i)^2$$

can be computed. In this case $E = R/\sigma^2 \sim \chi^2_V$ and $R \leq \sigma^2 \chi^2_V$ under the null hypothesis. We can construct the critical value of the standard error of β_i as $\sigma_c=(R/\chi^2_{V,\alpha})^{.5}$ where α is the desired significance level for χ^2_V.

The nonparametric statistical test for monopsony or monopoly power exertion can now be implemented in the form of a quadratic programming problem. In this test the constraint structure remains the same as with the linear programming problem, except that the market power parameter is no longer constrained to be positive. The objective function for the monopsony power case is replaced with

$$\text{(30)} \qquad \min_{m_i^{ts},\, a_i^{t+},\, a_i^{t-}} \quad R = \sum_{t=1}^{T} [(b^{t+} a_i^{t+} + b^{t-} a_i^{t-}) + \sum_{s \neq t}^{T} (m_i^{ts}/r_n^t \; - \; \beta_i^{ms})^2]$$

to incorporate the stochastic framework where β_i^{ms} is the hypothesized value of the monopsony Lerner index and other variables are defined as before. The monopsony case constraint is given in (24). Likewise, the objective function for the monopoly case becomes

$$\text{(31)} \qquad \min_{mp_i^{ts},\, a_i^{t+},\, a_i^{t-}} \quad R = \sum_{t=1}^{T} [(b^{t+} a_i^{t+} + b^{t-} a_i^{t-}) + \sum_{s \neq t}^{T} (mp_i^{ts}/r_n^t \; - \; \beta_i^{mp})^2]$$

where β_i^{mp} is the hypothesized value of the monopoly Lerner index. The corresponding monopoly case constraint is given in (26). The test employs a stochastic framework, unlike previously developed nonparametric market power tests. We construct the critical value of the standard error of β_i as $\sigma_c=(R/\chi^2_{V,\alpha})^{.5}$ where α is the desired significance level for χ^2_V. Using an approach analogous to maximum likelihood estimation, we then choose β_i that generates the lowest σ_c so β_i is most likely to have generated the observed data.

Data

Data used in this study consist of annual observations from the U.S. cigarette manufacturing industry for the period 1977 to 1993. Data and samples of TSP, SHAZAM, and GAMS programs used to generate the following results are available on request. Domestic cigarette production is taken from *USDA Tobacco Situation and Outlook* (TSO) as the sum of four types of cigarettes: standard cigarettes (70 mm nonfilter), filter tip cigarettes (80 mm), king (85 mm nonfiltered and filtered) and extra long (100 mm filter tip). Annual prices used to generate the Divisia price index are reported in TSO and are calculated by weighting corresponding wholesale cigarette price revisions by the fraction of the year that the price was in effect. Excise tax data are also taken from TSO. The Divisia price index for domestic production is constructed net of excise taxes.

Domestic tobacco price and quantity data are taken from various issues of TSO and consist of estimated leaf used for unstemmed flue-cured, unstemmed burley, and unstemmed Maryland tobacco. Prices used to calculate a Divisia price index for domestic tobacco are annual average prices received by growers for each tobacco type.

The source for imported tobacco data is the Department of Commerce's *U.S. Imports for Consumption and General Imports: FT246 and FT247*. The category of tobacco used in cigarette production is called cigarette leaf tobacco. It includes five types of tobacco: unstemmed Oriental, unstemmed flue-cured, unstemmed burley, stemmed tobacco except cigar leaf, and scrap tobacco except cigar leaf. Again, a Divisia price index is created using prices for each category computed from quantity and import value information.

Residual materials cost is calculated by subtracting the cost of domestic and imported tobacco from cost of materials as reported in the *Annual Survey of Manufacturers*, various issues. The price index of other materials is proxied by the producer price index for materials as reported in the

Economic Report of the President. A quantity index for other materials is constructed by dividing the residual materials cost by the producer price index for materials.

Data on advertising expenditures are taken from TSO, various issues. A quantity index for advertising is obtained by dividing the cigarette industry's reported annual expenditures on advertising by the cost per thousand advertising price index for magazines. The price index for magazines is chosen as a proxy for the cost per unit of advertising since magazine advertisements represent a major portion of advertising expenditures for cigarette manufacturers. This index is constructed from indices reported in USDA's *Food Marketing Review*, 1992-1993 and from various issues of *Advertising Age*.

Data regarding the cost of labor and the number of employees in cigarette manufacturing are taken from the *Annual Survey of Manufacturers*, various issues. Total compensation is divided by the number of employees to calculate average annual compensation per employee. A Divisia price index is then constructed to represent the price of labor.

Capital price is calculated as the annual cost per unit of capacity. Total capacity is the proxy for quantity of capital. Total capacity is recovered by dividing actual cigarette production by the capacity utilization rate as reported in *Annual Survey of Manufacturers, Current Industrial Reports, Tobacco and Tobacco Products*, various years. Annual total cost of capital is calculated assuming a 10 year depreciation rate of new capital expenditures (also from *Annual Survey of Manufacturers*) with no salvage value. A 5 year moving-average of Moody's Aaa corporate bond rate from the *Economic Report of the President* is used to estimate annual interest costs. Total annual capital service cost is the sum of depreciation charges and interest charges. Dividing total capital services cost by total capacity gives capital price per unit of capacity. We then construct indices for the price and quantity of capital.

Implementation

We estimate Hall's and Roeger's nonstructural monopoly market power tests and the analogous monopsony power counterparts for direct comparison to their original results and to results from nonparametric market power test results. We implement Ashenfelter and Sullivan's original method for comparison to their original results. Our revised version of Ashenfelter and Sullivan's method is employed for both monopsony and monopoly power. We also implement Love and Shumway's deterministic test and the statistical test developed in this paper. The nonparametric methods are employed to investigate both monopoly and monopsony power. Empirical equations for each test are given in the appendix.

Results

Table 1 compares our nonstructural model regression results with those of Hall and Roeger. Our data differs from that of Hall and of Roeger in that we use 4-digit industry level data rather than the more aggregated 2-digit industry level data. We also include cigarette manufacturers' advertising and input costs. Hall and Roeger estimate nearly identical markups of price over marginal cost (μ^{mp}). Our estimate of γ_H is higher than Hall's original estimate, implying lower market power exertion than his study suggests. However, neither Hall's estimate nor our estimate of γ_H is statistically significant. Our estimate of the market power index (β^{mp}) is very close to Roeger's estimate and is statistically significant. Hall and Roeger interpret the parameter estimate for μ^{mp} as signifying a positive markup of price over marginal cost, and hence, implying significant monopoly market power exertion.

Ashenfelter and Sullivan's nonparametric estimates of the lower bound for the "numbers equivalent of Cournot firms" (CNE) are presented in Table 2 (CNE-A). The CNE represents the least number of firms with Cournot behavior that the industry could support. Though there were only eight cigarette manufacturers in 1992, we also report results for n=9 and n=∞. It is possible that firms exhibit behavior more competitive than Cournot behavior which would result in a CNE greater than n=8. Table 2 also includes the CNE for Ashenfelter and Sullivan's method using our data(CNE-B), as well as the CNE using our revised versions of Ashenfelter and Sullivan's test where (a) all observations are compared except those where demand shifts occur (CNE-C) and (b) all observations are compared except those where demand shifts occur and all costs are incorporated (CNE-D). The CNE's from Ashenfelter and Sullivan's original study suggest that the cigarette industry has some monopoly power but is not a perfect cartel. For example, 70 percent of the observations support a CNE of four Cournot firms. The interpretation is that these observations support an industry with no less than four Cournot firms. This finding is about the same when we apply Ashenfelter and Sullivan's method to our data. In contrast, the support for small CNE's is much lower when the revised Ashenfelter-Sullivan method is applied to our data. Only 9 percent of the observations support a CNE of four Cournot firms when all observations are compared except when demand shifts occur without corresponding supply shifts. When all costs are included and demand shifts without supply shifts are omitted, a four firm CNE is supported by 35 percent of the observations.

Table 3 reports CNE's using the revised methods for both the monopoly and the monopsony power cases. The revised methods for monopsony omit domestic tobacco input supply shifts without corresponding input demand shifts. In the monopsony power test, 89 percent of the observations support a CNE of four Cournot firms when input costs other than domestic tobacco costs are omitted. When all input costs are included, the four-firm CNE increases to 98 percent. In other words, 98 percent of the observations, omitting supply shifts without demand shifts, support an industry of no less than four Cournot firms. We can also consider full collusive behavior, as defined by a CNE of 1 firm. The revised test, including all input costs, indicates that only 6 percent of the observations support a CNE of one firm for monopoly while 94 percent of the observations support a CNE of one firm for monopsony. This suggests that cigarette manufacturers' exhibit collusive behavior in purchasing of domestic tobacco, but they do not in the sale of cigarettes. As with the monopoly market power test, It appears that failure to account for all costs in the revised test may understate monopsony market power exertion. Results from the revised Ashenfelter and Sullivan method imply that it is monopsony power, rather than monopoly power, that is being exerted by cigarette manufacturers. Both tests of monopsony market power imply a much smaller number of CNE's in the industry than do the tests of monopoly market power.

A direct comparison of Hall, Roeger, Love and Shumway, and the statistical test can be obtained via the Lerner index. The comparison of Lerner index equivalents for monopoly and monopsony market power tests is presented in Table 4. Both Hall's and Roeger's methods indicate substantial monopoly power exertion by cigarette manufacturers (β^{mp} of 0.34 and 0.63, respectively). Results from the deterministic nonparametric test and the stochastic nonparametric test also support the hypothesis of monopoly power exertion. The deterministic test estimates β^{mp}=2.16 while the stochastic test estimates β^{mp}=2.2. It should be noted that, theoretically, the monopoly Lerner index has an upper bound of one. Empirically, it is possible for $\beta^{mp}>1$ because of noise not captured in the technical change variables or because of model misspecification. Given that our results from other tests indicate substantial monopsony power exertion, it is likely that misspecification (i.e. allowing market power exertion in only one direction) has inflated the monopoly Lerner index estimates.

Results from Love and Shumway's deterministic nonparametric test and the statistical nonparametric test support the hypothesis that cigarette manufacturers exert monopsony power in addition to monopoly power. Both tests give high estimates of monopsony market power exertion. The deterministic test estimates the monopsony Lerner index as 2.44 and the statistical test estimates the index as 3.61. It should be recalled that, unlike the monopoly Lerner index, the monopsony Lerner index is not bounded by 1.0.

Although Hall's and Roeger's estimates of the monopsony Lerner index are lower than those obtained from Love and Shumway's deterministic test and from the statistical test, each indicates substantial monopsony power exertion (β^{ms}=1.70 and β^{ms}=1.11, respectively). These results provide strong evidence that cigarette manufacturers exert monopsony power in addition to commonly assumed monopoly power.

Conclusions

Nonstructural and nonparametric market power tests are useful because they do not impose a functional form on the underlying behavioral equations. We develop nonstructural monopsony power tests analogous to nonstructural monopoly power tests developed by Hall; and by Domowitz, Hubbard, and Petersen; and Roeger. These nonstructural tests are implemented to test separately for monopoly and monopsony power exertion. Test results indicate that the cigarette manufacturing industry exerts both monopoly and monopsony power. Ashenfelter and Sullivan's test, in its original form, indicates a market structure for the cigarette manufacturing industry between collusion and competition with some monopoly power exertion. However, the test assumes a stable cost function and so does not include cost information by observation. It also compares only observations less than two periods apart in an effort to minimize bias from incorrectly attributing the effects of a demand shift to market power exertion. We revise the test by including cost information and omitting only comparisons where demand shifts clearly occur without corresponding supply shifts. With these admitted weaknesses of the test corrected and a similar test for monopsony developed, the revised tests indicate that monopsony power is pronounced while monopoly power is much lower than originally assessed. Love and Shumway's nonparametric deterministic test for monopsony market power is adapted to test for monopoly market power. A nonparametric statistical test is also developed to test for either monopsony or monopoly power exertion. Monopoly power estimates derived from these tests are substantial, as are monopsony power estimates. Monopsony power estimates indicate significant departures from competitive pricing in the input market for domestic unprocessed tobacco. Overall, our results suggest that not only do cigarette manufacturers deviate from marginal cost pricing in the sale of their output, but they also exert monopsony power in the procurement of domestic tobacco as an input.

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Table 1. Regression Results for Nonstructural Monopoly Tests[a]

DATA	Hall's Method			Roeger's Method		
	γ_H (β^{mp})	μ^{mp}_H	Adjusted R^2	β^{mp}	μ^{mp}_R	Adjusted R^2
2-digit	0.36 (1.88)	2.77	nr[b]	0.64 (23.05)	2.75	0.95
4-digit	0.68 (0.69)	1.46	0.70	0.63 (8.10)	2.71	0.80

[a]The subscript H denotes Hall's method and R denotes Roeger's method. μ^{mp}_H is calculated as $1/\gamma_H$ and μ^{mp}_R is calculated as $1/(1-\beta^{mp})$. t-statistics are in parentheses.
[b]Results for 2-digit industry level data are as reported by Hall and Roeger. We repeated their test using 4-digit data and advertising costs.
[c] Adjusted R^2 is not reported in Hall's study.

Table 2. Firm Numbers Equivalent (CNE) for Monopoly using Original and Revised Ashenfelter and Sullivan Approaches.

	Percent Consistent with Numbers Equivalent[a]			
Numbers Equivalent	CNE-A (v=702)	CNE-B (v=30)	CNE-C (v=128)	CNE-D (v=128)
n = 1	24.4	53.3	4.7	6.3
n = 2	45.2	53.3	4.7	7.0
n = 3	60.4	66.7	5.5	17.2
n = 4	69.7	73.3	8.6	35.2
n = 5	75.1	73.3	12.5	49.2
n = 6	79.3	73.3	14.1	54.7
n = 7	82.9	76.7	16.4	60.2
n = 8	85.2	80.0	22.7	67.2
n = 9	86.5	86.7	26.6	74.2
n = ∞	100.0	100.0	100.0	100.0

[a]Codes: v denotes number of observation pairs.

CNE-A denotes original A&S results comparing observations 2 years apart.

CNE-B denotes our application of original A&S method using 4-digit data and comparing observations not more than 2 years apart.

CNE-C denotes revised A&S method using 4-digit data and comparing all observations except those where demand shifts occur.

CNE-D denotes revised A&S method using 4-digit data, incorporating costs (including advertising), and comparing all observations except those where demand shifts occur.

Table 3. Firm Numbers Equivalent for Monopoly and Monopsony using Revised Ashenfelter and Sullivan Approach

	Percent Consistent with Numbers Equivalent			
	Cost omitted		Cost included	
Numbers Equivalent	Monopoly (v=128)	Monopsony (v=180)	Monopoly (v=128)	Monopsony (v=180)
n = 1	4.7	33.9	6.3	94.2
n = 2	4.7	65.1	7.0	96.8
n = 3	5.5	80.4	17.2	97.4
n = 4	8.6	89.4	35.2	97.9
n = 5	12.5	93.1	49.2	98.4
n = 6	14.1	93.7	54.7	98.9
n = 7	16.4	93.7	60.2	98.9
n = 8	22.7	95.2	67.2	98.9
n = 9	26.6	95.8	74.2	98.9
n = ∞	100.0	100.0	100.0	100.0

v denotes number of observation pairs included after omitting unmatched shifts in the opposing market.

Table 4. Monopoly and Monopsony Lerner Index Equivalents for Nonstructural and Nonparametric Tests[a]

		Monopoly	Monopsony
Method	**Type**	β^{mp}	β^{ms}
Hall	**Nonstructural**	0.34	1.70
Roeger	**Nonstructural**	0.63	1.11
Love and Shumway	**Deterministic Nonparametric**	2.16	2.44
Statistical Test	**Stochastic Nonparametric**	2.20 ($\chi^2_{128,.05}$)	3.61 ($\chi^2_{180,.05}$)

[a]Four-digit data were used.

Appendix A

The Solow residual is derived as follows:

1) Totally differentiate firm i's production function (16) with respect to time. The firm index i is dropped for notational simplicity.

(A1) $$\dot{y} = \dot{A} e^{\gamma} f(.) + A e^{\gamma} \dot{\gamma} f(.) + A e^{\gamma} (f_{x1} \dot{x}_1 + f_{x2} \dot{x}_2 + f_{x3} \dot{x}_3)$$

Divide by y:

(A2) $$\dot{y}/y = \dot{A}/A + \dot{\gamma} + A e^{\gamma} (f_{x1} \dot{x}_1 + f_{x2} \dot{x}_2 + f_{x3} \dot{x}_3)/y$$

Now let $\alpha_{xj} = f_{xj} x_{ji}/y_i = r_j x_{ji} /py, \ j = 1, 2, 3$. The last equality holds because all markets are assumed competitive. Appropriately substituting these definitions into equation (A2) gives

(A3) $$\dot{y}/y = \dot{A}/A + \dot{\gamma} + \alpha_{x1} \dot{x}_1/x_1 + \alpha_{x2} \dot{x}_x/x_2 + \alpha_{x3} \dot{x}_3/x_3$$

Now let $y/x_1 = y$, $x_2/x_1 = x_2$, $x_3/x_1 = x_3$. Using these definitions, it follows that $\dot{y}/y = \dot{y}/y - \dot{x}/x_1$. Also by constant returns to scale, α_{x1}, = 1 - α_{x2} - α_{x3}. Substituting these expressions into (A3) gives:

(A4) $$\dot{y}/y - \alpha_{x2} \dot{x}_2/x_2 - \alpha_{x3} \dot{x}_3/x_3 = \dot{A}/A + \dot{\gamma}$$

Equation (A4) gives the Solow residual.

Appendix B. Empirical Equations for Nonstructural and Nonparametric Market Power Tests.

METHOD	**Equation**[a]	**Parameters**	**Lerner Index Equivalent**
Hall–Monopoly[b]	$\dot{y}/y - \alpha_{Qagg}\dot{Q}_{agg}/Q_{agg} - \alpha_{us}\dot{Q}_{us}/Q_{us} = \dot{\gamma} + \beta^{mp}\dot{y}/y$	$\beta^{mp}, \dot{\gamma}$	β^{mp}
Hall-Monopsony[b]	$\dot{y}/y - \alpha_{Qagg}\dot{Q}_{agg}/Q_{agg} - \alpha_{us}\dot{Q}_{us}/Q_{us} = \dot{\gamma} + \beta^{ms}\dot{Q}_{us}/Q_{us}$	$\beta^{ms}, \dot{\gamma}$	β^{ms}
Roeger–Monopoly[c]	$[\dot{y}/y - \alpha_{Qagg}\dot{Q}_{agg}/Q_{agg} - \alpha_{us}\dot{Q}_{us}/Q_{us}] - [\alpha_{agg}\dot{P}_{agg}/P_{agg} + \alpha_{us}\dot{P}_{us}/P_{us} - \dot{p}/p]$ $= \beta^{mp}[\dot{y}/y + \dot{p}/p]$	β^{mp}	β^{mp}
Roeger–Monopsony[c]	$[\dot{y}/y - \alpha_{Qagg}\dot{Q}_{agg}/Q_{agg} - \alpha_{us}\dot{Q}_{us}/Q_{us}] - [\alpha_{agg}\dot{P}_{agg}/P_{agg} + \alpha_{us}\dot{P}_{us}/P_{us} - \dot{p}/p]$ $= \beta^{ms}\alpha_{us}[\dot{Q}_{us}/Q_{us} + \dot{P}_{us}/P_{us}]$	β^{ms}	β^{ms}
Original Ashenfelter & Sullivan--Monopoly	$\beta^{mp} \le \dfrac{-(p_f^{t} - et^{s})(y^{t} - y^{s})}{(p_f^{t} - p_f^{s})y^{s}} \;\; \forall \; t \neq s \text{ where } \lvert t-s \rvert = 2$	β^{mp}	β^{mp}
Revised Ashenfelter & Sullivan --Monopoly	$\beta^{mp} \le \dfrac{-[(p^{t})(y^{t} - y^{s}) + P_{us}^{t}(Q_{us}^{t} - Q_{us}^{s}) + P_{i}^{t}(Q_{i}^{t} - Q_{i}^{s}) + P_{l}^{t}(L^{t} - L^{s}) + P_{m}^{t}(M^{t} - M^{s}) + P_{a}^{t}(A^{t} - A^{s}) + P_{c}^{t}(C^{t} - C^{s})]}{(p^{t} - p^{s})y^{s}}$ $\forall \; t \neq s \text{ except when } p^{t} - p^{s} \overset{s}{=} y_i^{t} - y_i^{s}$	β^{mp}	β^{mp}

METHOD	**Equation**	**Parameters**	**Lerner Index Equivalent**
Revised Ashenfelter & Sullivan--Monopsony	$\beta^{ms} \le \frac{[(p^t)(y^t - y^s) - P_{us}^t(Q_{us}^t - Q_{us}^s) - P_i^t(Q_i^t - Q_i^s) - P_l^t(L^t - L^s) - P_m^t(M^t - M^s) - P_a^t(A^t - A^s) - P_c^t(C^t - C^s)]}{(P_{us}^t - P_{us}^s)Q_{us}^s}$ $\forall\ t \neq s \text{ except when } P_{us}^t - P_{us}^s \overset{s}{\neq} Q_{us}^t - Q_{us}^s$	β^{ms}	β^{ms}
Love and Shumway--Monopoly	$\min_{a_i^{t+}, a_i^{t-}, mp_i^{ts}} (b^{t+}a_i^{t+} + b^{t-}a_i^{t-} + \sum_{t=1}^{T} \sum_{s \neq t}^{T} c^{ts} mp_i^{ts})$ subject to: $p^t[(y_i^t - a_i^{t+} + a_i^{t-}) - (y_i^s - a_i^{s+} + a_i^{s-})] - mp_i^{ts}(y_i^t - y_i^s) - P_{us}^t(Q_{us}^t - Q_{us}^s) - P_i^t(Q_i^t - Q_i^s) - P_l^t(L^t - L^s) - P_m^t(M^t - M^s) - P_a^t(A^t - A^s) - P_c^t(C^t - C^s) \ge 0,$ $\forall\ s \neq t \text{ except when } p^t - p^s \overset{s}{=} y_i^t - y_i^s$ $mp_i^{ts} \ge 0\ \forall\ s \neq t$ $a_i^{t+},\ a_i^{t-} \ge 0,\ \forall\ t$	mp_i^{ts}, a_i^{t+}, a_i^{t-}	$\beta^{mp} = mp_i^{ts}/p^t$

METHOD	Equation	Parameters	Lerner Index Equivalent
Statistical Test--Monopoly	$\min_{mp_i^{ts},\, a_i^{t+},\, a_i^{t-}} \quad R=\sum_{t=1}^{T}[(b^{t+}a_i^{t+}+b^{t-}a_i^{t-})+\sum_{s\neq t}^{T}(mp_i^{ts}/p^t-\beta_i^{mp})^2]$ subject to: $p^t[(y_i^t-a_i^{t+}+a_i^{t-})-(y_i^s-a_i^{s+}+a_i^{s-})]-mp_i^{ts}(y_i^t-y_i^s)-P_{us}^t(Q_{us}^t-Q_{us}^s)$ $-P_i^t(Q_i^t-Q_i^s)-P_l^t(L^t-L^s)-P_m^t(M^t-M^s)-P_a^t(A^t-A^s)-P_c^t(C^t-C^s)\geq 0,$ $\forall\ s\neq t$ except when $p^t-p^s \overset{S}{=} y_i^t-y_i^s$ $a_i^{t+},\ a_i^{t-}\geq 0,\ \forall\ t$	mp_i^{ts}, a_i^{t+}, a_i^{t-}	$\beta^{mp}=mp_i^{ts}/p^t$
Love and Shumway--Monopsony	$\min_{a_i^{t+},a_i^{t-},m_i^{ts}} \quad (b^{t+}a_i^{t+}+b^{t-}a_i^{t-}+\sum_{t=1}^{T}\sum_{s\neq t}^{T}c^{ts}m_i^{ts})$ subject to: $p^t[(y_i^t-a_i^{t+}+a_i^{t-})-(y_i^s-a_i^{s+}+a_i^{s-})]-P_{us}^t(Q_{us}^t-Q_{us}^s)-P_i^t(Q_i^t-Q_i^s)-P_l^t(L^t-L^s)$ $-P_m^t(M^t-M^s)-P_a^t(A^t-A^s)-P_c^t(C^t-C^s)-m_i^{ts}(Q_{us}^t-Q_{us}^s)\geq 0,$ $\forall\ s\neq t$ except when $P_{us}^t-P_{us}^s \overset{S}{\neq} Q_{us}^t-Q_{us}^s$ $m_i^{ts}\geq 0,\ \forall\ s\neq t$ $a_i^{t+},\ a_i^{t-}\geq 0,\ \forall\ t$	m_i^{ts}, a_i^{t+}, a_i^{t-}	$\beta^{ms}=m_i^{ts}/P_{us}^t$

METHOD	Equation	Parameters	Lerner Index Equivalent
Statistical Test--Monopsony	$\underset{m_i^{ts},\ a_i^{t+},\ a_i^{t-}}{\text{Min}} \quad R = \sum_{t=1}^{T}[(b^{t+}a_i^{t+} + b^{t-}a_i^{t-}) + \sum_{s \neq t}^{T}(m_i^{ts}/P_{us}^{t} - \beta_i^{ms})^2]$ subject to: $p^{t}[(y_i^{t} - a_i^{t+} + a_i^{t-}) - (y_i^{s} - a_i^{s+} + a_i^{s-})] - P_{us}^{t}(Q_{us}^{t} - Q_{us}^{s}) - P_i^{t}(Q_i^{t} - Q_i^{s}) - P_l^{t}(L^{t} - L^{s})$ $- P_m^{t}(M^{t} - M^{s}) - P_a^{t}(A^{t} - A^{s}) - P_c^{t}(C^{t} - C^{s}) - m_i^{ts}(Q_{us}^{t} - Q_{us}^{s}) \geq 0,$ $\forall\ s \neq t$ except when $P_{us}^{t} - P_{us}^{s} \overset{s}{\neq} Q_{us}^{t} - Q_{us}^{s}$ $a_i^{t+},\ a_i^{t-} \geq 0,\ \forall\ t$	m_i^{ts}, a_i^{t+}, a_i^{t-}	$\beta^{ms} = m_i^{ts}/P_{us}^{t}$

[a]Variable definitions:

p	Domestic wholesale price of cigarettes, net of excise tax (Divisia index)
y	Domestic quantity of cigarettes produced (1000's)
P_{us}	Domestic price per lb. pd to producers (Divisia index)
Q_{us}	Domestic tobacco purchased by cigarette manufacturers (lbs)
P_i	Price of tobacco imports (Divisia index)
Q_i	Imported tobacco for cigarettes (lbs)
P_l	Average annual compensation of workers in cigarette manufacturers ($'s)
L	Annual # of workers employed by cigarette manufacturers
P_m	Price of materials other than tobacco (PPI for containers)
M	Materials other than tobacco
P_a	Price per unit of advertising (PPI for magazine advertising)
A	Quantity of Advertising per year
P_c	Price per Unit of Capacity
C	Total annual capacity
P_{agg}	Price index of variable inputs in aggregate (Divisia index, excludes domestic tobacco and capacity)
Q_{agg}	Quantity of variable inputs in aggregate (created from Divisia index, excludes domestic tobacco and capacity)

[b]Quantities are normalized by C
[c]Prices are normalized by Pc

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