### Title
Can market power be estimated?




### Authors
Hyde, Charles
Perloff, Jeffrey M



### Publication Date
1993-06-01

689

CUDARE

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

WORKING PAPER NO. 689

# CAN MARKET POWER BE ESTIMATED?

by

Charles Hyde
and
Jeffrey M. Perloff



California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
June, 1993

# Can Market Power be Estimated?

Charles Hyde

Jeffrey M. Perloff

July 1993

We thank Wayne Gray for generously providing data and James Chalfant for helpful discussions on estimating nonlinear models. Shazam 7.0 was used for both simulations and estimations.

## Can Market Power be Estimated?

In the last decade and a half, several new approaches to estimating or testing market structure were developed. We examine how well three of the best-known and widely-used approaches — structural models, Panzar and Rosse (1987), and Hall (1986) — work.

The methods differ in their data requirements and the types of assumptions one must maintain. The structural model requires more data and more explicit assumptions than the other two methods. If correctly specified, it is the most flexible and powerful approach. There is no way of knowing, of course, if it is correctly specified. As anyone who has tried to estimate such a system knows, the estimate of market power is extremely sensitive to small changes in specification. Moreover, frequently the necessary data are not available. Thus, alternative approaches that require less data and are less sensitive to specification error would be very useful.

All three methods are internally consistent and mathematically correct. Our question, however, concerns whether they are practical and powerful. We examine all three methods using simulation models. We then apply the Panzar-Rosse and Hall methods to actual data to determine if they produce similar answers.

### The Three Approaches

All three approaches can be used to test whether a market is competitive. The structural approach and one version of Hall's method can be used to obtain a measure of the gap between price and marginal cost: a direct measure of the market structure.

*Structural Model*

The structural model approach is widely used.[1] It requires one to estimate all the underlying structural equations of the market. If only aggregate data are available, one might estimate a demand equation, an aggregate cost equation, and an equilibrium condition.

To illustrate this approach, suppose the demand curve is

$$p = p(Q; Z), \tag{1}$$

where $p$ is price, $Q$ is market output, and $Z$ is a vector of other relevant variables such as income, prices of substitutes, and so forth.

We can use a parameter $\lambda$ to nest various market structures (Just and Chern 1980, Bresnahan 1982, and Lau 1982). For example, we can define an "effective" marginal revenue function as

$$MR(\lambda) = p + \lambda p_Q Q, \tag{2}$$

where $p_Q$ is the slope of the demand curve. If $\lambda = 0$, marginal revenue equals price and the market is competitive; if $\lambda = 1$, marginal revenue equals the marginal revenue of a monopoly; if $\lambda$ lies between 0 and 1, the degree of market power lies between that of monopoly and competition. With $n$ identical firms playing Cournot, $\lambda$ equals $1/n$.

The optimality or equilibrium condition is that the industry sets its effective marginal revenue equal to its marginal cost,

---

[1] For a list of many studies that used structural models see Bresnahan (1989) or Carlton and Perloff (1994) chapter 9.

$$MR(\lambda) = p + \lambda p_Q Q = MC(Q; W), \qquad (3)$$

where $MC$ is a function of output and other variables, $W$.[2]

This approach has two chief weaknesses. First, one must correctly specify all the underlying structural equations. Second, as Bresnahan (1982) and Lau (1982) show, $\lambda$ is not identified for some specifications (including linear and log-linear demand curves). In our simulations, we pick specifications where $\lambda$ is identified.

*Hall*

Hall's (1986) method is very clever and widely used.[3] He uses comparative statics results to test for market power where the null hypothesis is competition. The key weakness of his approach, which he discusses at length, is that one must maintain the assumption of constant returns to scale (CRS). Thus, his test is actually a joint test of both competition and CRS. We examine how well his approach works under CRS and under increasing or decreasing returns to scale.

Hall uses two approaches. In his "instrument test," he tests whether the market is competitive by examining whether an instrument (variable) is correlated with the Solow residual, $\theta$. The estimated equations are of the form

---

[2] The most obvious interpretation of $\lambda$ is a summary measure of the gap between $p$ and $MC$. That is, $\lambda$ is the outcome of some unknown game. Alternatively, some empirical researchers estimate a related conjectural variation parameter. Bresnahan (1991) and Carlton and Perloff (1994) discuss the alternative interpretations.

[3] Shapiro (1987) and Domowitz et al. (1986, 1988) and others use Hall's estimation methods. Shapiro (1987) discusses some of the conceptual limitations to his approach and possible solutions.

$$\theta = \phi_0 + \phi_1 I + \varepsilon,$$

where $I$ is the instrument (such as the change in the level of military spending, price of crude oil, money supply, or population). This approach does not provide any information about the market structure if the market is not competitive.

In his "estimation method," he estimates the markup $\mu = p/MC$. Using this method, the test for competition is whether $\mu = 1$. For example, one might estimate the equation

$$\Delta \ln\left(\frac{Q}{K}\right) = \mu\left[\alpha \Delta \ln\left(\frac{L}{K}\right) + \beta \Delta \ln\left(\frac{M}{K}\right)\right] + \varepsilon,$$

where $L$ is labor, $K$ is capital, $M$ is the material input, $\alpha = wL/pQ$ is labor's share in output value, $\beta = mM/pQ$, and $m$ is the price of materials. If the market is not competitive, $\mu > 1$, however, it is difficult to interpret $\mu$ unless one has additional information such as demand elasticities (Shapiro 1987).

*Panzar-Rosse*

Rosse and Panzar (1977) and Panzar and Rosse (1987) present an extremely clever method for testing for market power. Their work has been very influential in the development of other approaches.[4]

---

[4] The method is applied in Rosse and Panzar (1977) and Shaffer (1982). Other important approaches that bear some resemblance to this one include three studies of the cigarette industry by Sumner (1981), Sullivan (1985), and Ashenfelter and Sullivan (1987).

To conduct the test, one estimates a reduced-form revenue function and then calculates a test statistic, *H*, which is the sum of the elasticities of revenue with respect to each of the factor prices. For certain specific models, Rosse and Panzar (1987) show:

- Monopoly Rent Hypothesis: Under monopoly, *H* is nonpositive.
- Market Equilibrium Hypothesis (symmetric Chamberlinian monopolistic competition): If firms maximize profits and there are market forces (entry) that drive profits to zero, $H \leq 1$.
- Competition Hypothesis: For firms in long-run competitive equilibrium with free entry, $H = 1$.

As Panzar and Rosse point out, to conduct their test, one must develop alternative models. For example, they illustrate how one can test for monopoly versus various competitive and oligopolistic alternatives. Based on their analytic results, it is not possible to distinguish monopolistic competition from either competition or monopoly.

We ran into two problems using their test. First, for most demand and cost functions, the correct reduced-form revenue function is extremely complicated and nonlinear; hence, it is difficult to estimate. Estimating "approximate" reduced-form equations can lead to biased results of course. In our simulations, we calculate the true *H* statistic and use an approximation of the revenue function to estimate an approximate *H* statistic.

Second, as Panzar and Rosse note, the test is inherently powerless for the Cobb-Douglas specification. In our simulations, we generalized the standard log-linear, Cobb-Douglas specification to include some interaction terms, however, that does not eliminate the difficulty. The problem is that the test statistic is independent of the market structure parameter, as we show below.

Given our choice of simulation models, it may appear that we are slanting our experiments against this approach; however, doing so was not our intention. Indeed, because this test is relatively easy to use, if it were powerful, it would certainly be extremely attractive.

## Simulation Model

We examine these approaches to estimating and testing market power using two simulation models: a Cobb-Douglas model and a linear model. Little additional information is gained for the structural and Hall approaches from using both models, so we concentrate on only one of these models, the Cobb-Douglas. The linear model is described in the Appendix 1.

All the equations in the Cobb-Douglas model are log-linear. The production function is

$$Q = AL^{\alpha}K^{\beta}e^{\varepsilon}, \tag{4}$$

where $\varepsilon$ is a random variable, which is related to the random variables discussed below. The scale parameter, $\gamma$ equals $\alpha + \beta$ (where $\alpha$ and $\beta$ are not the same as in the discussion of the Hall model above unless the market is competitive).

The corresponding cost function is

$$C = A^{-\frac{1}{\gamma}}\gamma\left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\gamma}}\left(\frac{r}{\beta}\right)^{\frac{\beta}{\gamma}}Q^{\frac{1}{\gamma}}e^{\varepsilon_C} \equiv C^{*}e^{\varepsilon_C}, \tag{5}$$

where $\varepsilon_C \sim N(0, \sigma^2)$ and a "*" indicates the systematic part of a variable ($C^*$ is the systematic portion of costs that does not depend on $\varepsilon_C$). The marginal cost is

$$MC = A^{-\frac{1}{\gamma}} \left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\gamma}} \left(\frac{r}{\beta}\right)^{\frac{\beta}{\gamma}} Q^{\frac{1-\gamma}{\gamma}} e^{\varepsilon_C} \equiv MC^* e^{\varepsilon_C}. \tag{6}$$

The factor demands are

$$L = A^{-\frac{1}{\gamma}} \left(\frac{\alpha}{w}\right)\left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\gamma}} \left(\frac{r}{\beta}\right)^{\frac{\beta}{\gamma}} Q^{\frac{1}{\gamma}} e^{\varepsilon_L} = L^* e^{\varepsilon_L}, \tag{7}$$

$$K = A^{-\frac{1}{\gamma}} \left(\frac{\beta}{r}\right)\left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\gamma}} \left(\frac{r}{\beta}\right)^{\frac{\beta}{\gamma}} Q^{\frac{1}{\gamma}} e^{\varepsilon_K} = K^* e^{\varepsilon_K}. \tag{8}$$

As a result,

$$\frac{L}{K} = \frac{\alpha}{\beta}\frac{r}{w} e^{\varepsilon_L - \varepsilon_K}.$$

The demand is also log-linear:

$$\ln p = \delta_O - (\delta_1 + \delta_2 Z) \ln Q + \varepsilon_D \equiv \ln p^* + \varepsilon_D, \tag{9}$$

where $p$ is price, $Z$ is a variable that rotates the demand curve (such as the price of a substitute, a proxy for taste changes, or income), and $\varepsilon_D \sim N(0, \sigma^2)$.[5] The slope of the demand curve is $p' \equiv p_Q = -(p/Q)(\delta_1 + \delta_2 Z)$.

---

[5] As Bresnahan (1982) and Lau (1982) show, $\lambda$ is not identified in a log-linear model without such an interaction term that rotates the demand curve.

The effective marginal revenue is

$$MR(\lambda) = p + \lambda p' Q = p\left[1 - \lambda(\delta_1 + \delta_2 Z)\right]. \tag{10}$$

For effective marginal revenue to be positive (for the equilibrium to make sense), $\lambda(\delta_1 + \delta_2 Z)$ must be less than one. That is, the inverse of the "effective elasticity of demand," which is $\lambda$ times the inverse of the absolute value of the elasticity of demand, must be less than one.

The equilibrium condition is that effective marginal revenue equals marginal cost, or

$$\ln MR(\lambda) = \ln p + \ln\left[1 - \lambda(\delta_1 + \delta_2 Z)\right] = \ln MC. \tag{11}$$

Substituting for $MC$ from Equation (6) and for $p$ from Equation (9), output demanded is

$$\ln Q = \frac{\delta_0 + \ln(1 - \lambda(\delta_1 + \delta_2 Z)) + \frac{1}{\gamma}\ln A - \frac{\alpha}{\gamma}\ln\left(\frac{w}{\alpha}\right) - \frac{\beta}{\gamma}\ln\left(\frac{r}{\beta}\right) + \varepsilon_D - \varepsilon_C}{\delta_1 + \delta_2 Z + \frac{1-\gamma}{\gamma}}$$
$$\equiv \ln Q^* + \frac{\varepsilon_D - \varepsilon_C}{\delta_1 + \delta_2 Z + \frac{1-\gamma}{\gamma}}. \tag{12}$$

Thus, given specified parameters, $Q^*$ is obtained using Equation (9). By substituting $Q^*$ into Equations (7), (8), and (9), $L^*$, $K^*$, and $p^*$ are obtained.

Panzar and Rosse require that we estimate a reduced-form revenue equation. In this model, the logarithm of revenue, $\ln R = \ln p + \ln Q$, is

$$\ln R = \delta_0 + \varepsilon_D - (\delta_1 + \delta_2 Z) \times \left[ 1 + \frac{\delta_0 + \ln(1 - \lambda(\delta_1 + \delta_2 Z)) + \frac{1}{\gamma}\ln A - \frac{\alpha}{\gamma}\ln\left(\frac{w}{\alpha}\right) - \frac{\beta}{\gamma}\ln\left(\frac{r}{\beta}\right) + \varepsilon_D - \varepsilon_C}{\delta_1 + \delta_2 Z + \frac{1-\gamma}{\gamma}} \right]. \quad (13)$$

That is, $\ln R$ is linear in the log of the factor prices (for given $Z$) and nonlinear in $Z$. More importantly, the coefficients on the factor prices do not depend on $\lambda$. Thus, the Panzar-Rosse test statistic, $H \equiv \partial(\ln R)/\partial(\ln w) + \partial(\ln R)/\partial(\ln r)$, is independent of $\lambda$ and cannot be used to distinguish market structures. For this model,

$$H = \frac{(\delta_1 + \delta_2 Z - 1)(\alpha + \beta)}{\gamma\left(\delta_1 + \delta_2 Z + \frac{1-\gamma}{\gamma}\right)}. \quad (14)$$

In contrast, $H$ is a function of $\lambda$ in the linear model as shown in Appendix 1.

## Simulation Results

We consider three market structures: competition ($\lambda = 0$, $\mu = 1$), four-identical Cournot firms ($\lambda = .25$), and collusion ($\lambda = 1$). The parameters in the simulations are $A = 1.2$, $\alpha = 1/3$, $\beta = 2/3$, $\delta_0 = 1.8$, $\delta_1 = 1.2$, and $\delta_2 = -0.5$. The errors $\varepsilon_C$ and $\varepsilon_D$ are distributed 0.1N(0, 1). There were 35 observations in each simulation. The simulations are based on the wage, $w$, and the user cost of capital, $r$, for U. S. manufacturing 1947-1981 (Berndt and Wood 1986). The producer price index for processed foods and farm products, $Z$, is from the *Economic Report of the President.*

### *Structural Model*

As expected, the structural model works well if it is correctly specified (Cobb-Douglas model) and does not work as well if it is incorrectly specified (linear model).

When correctly specified, no particular problems are associated with the scale parameter $\gamma$, so we concentrate on the model with constant returns to scale ($\gamma = 1$). That model is estimated using nonlinear three-stage least squares, where the instruments are *w*, *r*, *z*, and the instruments described below.

The structural model simulation results are sensitive to the size of the error terms. In Table 1, the variance of price for the model based on $\varepsilon_C$ and $\varepsilon_D$ errors that are distributed 0.1N(0, 1) is virtually identical to that of the manufacturing sector (after normalizing so that the means of the two series are equal). The variance of price for the model based on error terms that are ten times larger, N(0, 1), is 13% larger.

We use t-statistics to test whether the estimated market structure parameter $\lambda$ equals 0, 0.25, or 1 (competition, four-firm Cournot, and collusion). The results for both the true Cobb-Douglas model and the misspecified linear model are shown in Table 1 based on 1,000 simulation of each example. The table shows the percentage of simulations in which we cannot reject ("accept") each hypothesis about $\lambda$ based on a standard two-tail test.[6]

With the smaller error terms, in the correctly specified (Cobb-Douglas) model, we reject the false hypotheses in all cases. We fail to reject the correct hypothesis in 95.5% of the 1,000 simulations when the market is competitive ($\lambda = 0$), 94.6% when there are four identical Cournot firms ($\lambda = 0.25$), and 97.6% when the market is collusive ($\lambda = 1$).

If we use the incorrectly specified linear model, we cannot distinguish clearly between the hypotheses. We fail to reject all three hypotheses when $\lambda$ is 0.25 or 1.

---

[6] Some might argue for using one-tailed tests, especially when testing the competitive and collusive hypotheses. The same pattern of results, however, would be observed.

When the model is competitive, we fail to reject the true hypothesis that $\lambda = 0$ in 83.3% of the simulations; however, we also fail to reject $\lambda = 0.25$ in 81.2% and $\lambda = 1$ in 57% of the simulations.

Where the model is misspecified, the results are very sensitive to the scale parameter $\gamma$. With $\gamma = 0.9$ or 1.1, we reject all the hypotheses in almost all cases.[7]

When the larger error terms are used with the correct specification, the probability of incorrectly accepting false hypotheses rises, as one would expect. The probability of accepting true hypotheses are about the same as in the model with the smaller error terms except for the collusion model, where the probability of accepting the true hypothesis drops by 11.7 percentage points.

*Hall*

In both of Hall's approaches, one can test whether the market is competitive (given constant returns to scale). In the estimation method, after estimating the price-marginal cost markup $\mu$, one uses t-statistics to test the hypothesis that $\mu = 1$. In the instrument test, one uses instrumental variables to test the competitive hypothesis.

In the estimation method, if the market is not competitive, $\mu$ is greater than one, but the relationship between $\mu$ and particular market structures is not known unless one has additional information such as the demand elasticity (Shapiro 1987). In Table 2, the second column shows the average estimate of $\mu$ across the simulations for each of the three market structures. The third column shows the average price-marginal cost ratio based on the true simulation model. When the market is competi-

---

[7] The exception is when $\lambda = 0.25$ and $\gamma = 0.9$, where we fail to reject the hypothesis $\lambda = 0$ in 81.9% of the simulations and $\lambda = 0.25$ in 43.4% of the simulations.

tive, the average estimate of $\mu$ is 1. When the market is not competitive ($\lambda = 0.25$ or 1), however, the mean value of $\mu$ is less than the true price-marginal cost ratio.

The last two columns show the percentage of simulations in which we fail to reject various null hypotheses using the smaller error terms: 0.1N(0, 1). The test for competition is the test that $\mu = 1$. Hall's test correctly fails to reject ("accepts") the hypothesis 98.4% of the time when the market is competitive; however it incorrectly fails to reject in 12.1% of the simulations when $\lambda = 0.25$ and 6.2% when $\lambda = 1$. The last column tests whether the estimated $\mu$ equals the average *p/MC* (which, of course, one could not know in a real-world problem). Again, it shows that the estimated $\mu$ in the collusive case is very low.

Unlike the structural model, Hall's model is very sensitive to the size of the errors. When the larger errors are used, N(0, 1), we fail to reject competition in virtually all cases.

As Hall discusses at length, his test is actually a test of the joint hypotheses of competition and constant returns to scale. To see how sensitive this approach is to deviations from constant returns to scale, we allow $\gamma$ to range between 0.8 and 1.2 using 0.1 increments. For each $\gamma$, the model is simulated 200 times.

The thick, solid line in Figure 1 shows how the mean of the estimates of $\mu$ varies with $\gamma$ when the true model is price taking ($\lambda = 0$).[8] When there are decreasing returns to scale ($\gamma < 1$), the estimate of $\mu$ is well above 1; and, with increasing returns to scale ($\gamma > 1$), $\mu$ is well below 1. Also shown in Figure 1 are two dotted lines that show, for a given $\gamma$, the mean $\mu$ plus or minus 2 standard deviations. Based on this

[8] The competitive model does not make sense for $\lambda = 0$ when there are increasing returns to scale; however, one can imagine that this equilibrium is the outcome of Bertrand (price taking) behavior by oligopolists, which leads to $\lambda = 0$.

example, relatively small deviations from constant returns can affect hypothesis tests of competition substantially. Hall's test works well, however, with constant returns to scale.

Figure 2 shows the same thick solid line for the mean $\mu$ for the $\lambda = 0$ model as in Figure 1. It also shows the corresponding lines for the average $\mu$ when $\lambda = 0.25$ or $\lambda = 1$. The average $\mu$ line for the collusive model is slightly lower than the dotted line shown in Figure 1 for the average $\mu$ for the $\lambda = 0$ model plus 2 standard deviations. As Figure 2 shows, with increasing returns to scale, a collusive market could be mistaken for a competitive one. Similarly, with decreasing returns to scale, falsely rejecting competition becomes more likely.

We also examine Hall's instrumental variable test of the competitive hypothesis. It is not obvious how we should construct the instrument. Following a suggestion on how to choose instrument's from Hall's paper, we use an instrument, *I*, that is the weighted average, $\omega\Delta n + (1 - \omega)\zeta$, of a random error term, $\zeta \sim N(0, 0.1)$, and the change in the logarithm of the labor/capital ratio, $n = \ln(L/K)$.[9]

The outcome of these experiments using $\omega = 0.1$, 0.5, and 0.9 are shown in Table 3. The table shows how the instrument is correlated with $\Delta n$ and with the Solow residual, $\theta$. Based on this test for all $\omega$, we almost never reject the competitive hypothesis when the true model is competition. We are likely to fail to reject ("accept") the competitive hypothesis incorrectly when the instrument is not highly correlated with $\Delta n$ and $\theta$. We do reject competition correctly if the instrument is highly correlated with $\Delta n$ and $\theta$.

---

[9] We also experimented with instruments created by using random error terms that were correlated with the errors in the labor equation. This approach, however, did not work well.

In Figure 3 where $\omega = 0.2$ and $\lambda = 0$ (competition) presents various tests of competition. The thick, solid line shows the percent of cases in which competition is rejected based on a standard two-tailed t-test. As Hall notes, however, there is no plausible interpretation of a negative correlation, so one might one want to use a one-tailed test (shown as a dashed line). The dotted line shows the actual number of negative correlations. Again, with constant returns to scale, Hall's test works well. With decreasing returns to scale, competition is incorrectly rejected in a higher percent of cases.

For larger $\omega$, the two-tail test rejects competition in virtually all cases for any $\gamma$ much different than 1. For example, if $\omega = 0.5$, the competitive hypothesis is accept virtually all of the time when $\gamma \,\varepsilon\, (0.98, 1.02)$ and rejected in virtually all simulations for other $\gamma$.

With increasing returns to scale, finding an implausible negative correlation between the Solow residual and the instrument is very likely. Based on a one-tailed test, one would not reject competition; however, based on a two-tailed test, one might incorrectly reject competition because the correlation is too negative. Figure 3 shows that the probability of getting a negative correlation is virtually zero for $\gamma$ much below one, and the probability is virtually one for $\gamma$ more than slightly greater than one.

*Panzar-Rosse*

It is not obvious how to conduct a "fair" test of the Panzar-Rosse approach. If one estimates the true structural model (and the model is one in which the market structure is identified), then the Panzar-Rosse test has the properties that they show analytically. On the other hand, if one estimates the true structural model, there is no need to conduct their test as one has an estimate of the actual market structure.

Panzar and Rosse suggest estimating a reduced-form revenue equation, which is substantially easier and requires less data than estimating a full structural model. Unfortunately, there are practical problems with this approach. First, as mentioned above, for some specification (such as the Cobb-Douglas), their tests do not discriminate between the market structures. Second, even with the fairly simple Cobb-Douglas or linear models, the correct reduced-form revenue equation is highly nonlinear and complex. If one uses a simpler reduced form, the estimates may be biased.

We use the linear example described in Appendix 1.[10] The actual *H* (the sum of the factor cost elasticities) statistics are -3.48 when $\lambda = 0$, -5.90 when $\lambda = 0.25$, and -12.31 when $\lambda = 1$. In other words, *H* varies with $\lambda$ but is always negative.[11] This result is consistent with Panzar and Rosse's theorem that *H* is negative for the monopoly case. Unfortunately, for this model, *H* is also negative (though closer to zero) for less collusive market structures including competition.[12]

---

[10] The parameters are $\alpha = \beta = 10$, $\gamma = 0$ (CRS), $\phi_0 = 40$, $\phi_1 = 2$, $\phi_2 = 1.5$, and $\eta = 0$. The errors, $\zeta_C$ and $\zeta_D$, are distributed 0.1N(0.1).

[11] In contrast, as we showed analytically, *H* is a constant with respect to $\lambda$ for the Cobb-Douglas model. In the model with the larger errors, $H = -2.10$ for all $\lambda$.

[12] A test more favorable to the Panzar-Rosse approach would have the property that $H < 0$ for collusion and *H* is positive (or even better, equal to a specific positive value) for competition. Unfortunately, we could not find a simple model (one that can be analytically solved) that had this property and let us nest many market structures in a single parameter.

With the linear model, we estimate the *H* statistic using these two approximate reduced forms. We use a simple linear and a log-linear approximation of the reduced form:

$$R = \phi_0 + \phi_1 w + \phi_2 r + \phi_3 z,$$

and

$$\ln R = \phi_0 + \phi_1 \ln w + \phi_2 z \ln w + \phi_3 \ln r + \phi_4 z \ln r + \phi_5 \ln z + \phi_6 z \ln z.$$

We use two-tailed t-tests to compare *H* to 0 and 1. Based on the two approximation specifications, we always fail to reject ("accept") that *H* is negative for the competitive model. That is, we accept a condition that Panzar and Rosse show is necessary but not sufficient for the market to be monopolized. The hypothesis that $\lambda$ = 1 (free-entry competition) is always rejected.

When $\lambda = 0.25$, both the hypotheses ($H < 0$, $H = 1$) are rejected for the linear approximation. For the log-linear approximation, the $H < 0$ hypothesis never is rejected, and the $H = 1$ hypothesis always is rejected. Strangely, both hypotheses are rejected for the collusive model ($\lambda = 1$), using either approximation.

**Empirical Studies**

We tried to compare the three methods using four-digit Standard Industrial Code (SIC) data for food, beverages, and tobacco industries.[13] Unfortunately, we were unsuccessful in obtaining plausible estimates based on a structural model: The

---

[13] See Appendix 2 for a description of the data and sources. All prices are deflated by the GNP deflator.

estimated price-cost margins, $\lambda$, were negative for many industries.[14] In Table 4, we compare and contrast the Panzar-Rosse and the Hall estimates, where the production function depends on labor, capital, materials, and energy.

*Hall's Instrument Test*

We used five instruments in Hall's instrument test for competition. For three instruments — the party of the President, the percentage change in military expenditures, and the percentage change in the U. S. population — the hypothesis of competition could not be rejected for any industry (these t-statistics are not reported in the Table 4). For the other two instruments (the percentage change in the price of oil and the percentage change in the M1 money supply), the t-statistics on this test are shown in Table 4. A "*" indicates that we reject the null-hypothesis that the coefficient on the instrument is zero at the 5% level based on a two-tailed test.

In three cases (flour and malt beverages for oil and fluid milk for M1), the estimated coefficient on the instrument is statistically significantly negative. This result is difficult to explain, though it presumably is consistent with competition. Using oil as the instrument, we never reject competition (no coefficient is statistically significantly positive). Using M1 as the instrument, we reject competition for flour and malt beverages.

---

[14] We estimated systems of AIDS demand equations and used the same functional form for the marginal cost for each equation. By experimenting with the specification for each industry, we probably could estimate separate specifications with plausible results for most of the industries. We did not want to use different specifications for each industry, however; nor did we want to extensively experiment with the specification, thereby creating a pretest estimator bias.

*Hall's Estimation Method*

We also estimated Hall's markup (last column of Table 4).[15] The asymptotic standard errors are shown under the point estimates of $\mu$. A "#" indicates that we reject the null-hypothesis that $\mu = 1$ (competition) at the 0.05 level using an asymptotic, two-tailed test. The estimated $\mu$ for red meat and flour are statistically significantly less than 1 (indeed, the point estimates are negative), which is implausible. On the basis of an asymptotic, two-tailed test, none of the estimates of $\mu$ is statistically significantly larger than 1. Using a one-tailed test, we reject competition for cigarettes. If we were to use only labor and capital (ignore materials and energy), we would reject the competition hypothesis for red meat, poultry, cheese, flour, malt beverages, distilled liquor, cigarettes, and cigars.

*Panzar-Rosse*

We use both a linear and a log-linear specification of the reduced-form revenue equation for the Panzar-Rosse test:

$$R = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 m + \alpha_4 w + \alpha_5 r + \alpha_6 e + \alpha_7 nd,$$

$$\ln R = \alpha_0 + \alpha_1 t + \alpha_2 \ln t^2 + \alpha_3 \ln m + \alpha_4 \ln w + \alpha_5 \ln r + \alpha_6 e + \alpha_7 \ln nd,$$

where $t$ is a time trend (1, 2, ...), $m$ is the price of materials, $w$ is the wage rate, $r$ is the cost of capital, $e$ is the price of energy, and $nd$ is a price deflator for nondurables.

The Panzar-Rosse results are in the first two columns of Table 4. Below the estimates of $H$ are the standard errors. The hypothesis that $H$ equals one (competition with free entry) is rejected for several industries under both specification. In the

---

[15] In estimating the mark-up equations, instrumental variables (a time trend and first differences of military expenditures, crude oil price, money supply, political party of the president, and U.S. population) were used.

logarithmic specification, the *H* for no industry is statistically significantly less than zero (indeed, none of the point estimates is negative). In contrast, in the linear specification, several of the *H* point estimates are negative, and one, malt beverages, is statistically significantly less than one at the 5% level. In short, the results are sensitive to the specification of the reduced-form equation.

The results are also sensitive to whether materials and energy are included along with labor and capital. In the linear specification with only labor and capital, the *H* statistic is statistically significantly negative for cheese and flour (a result consistent with collusion). It is statistically significantly positive for cigars (a result inconsistent with collusion).

In short, both the Panzar-Rosse and Hall methods are sensitive to the functional form and the number of factors included. For poultry, butter, cheese, we cannot reject competition based on any of the tests shown in Table 4. For all other industries, one or more tests rejects competition or are implausible (Hall estimate of $\mu$ for red meat and flour). For these other industries, there is little consistency in results across the methods, though, in most cases, the results are consistent with some form or another of oligopoly or monopolistic competition.

## Conclusions

Each of the three methods of estimating or testing market power has both strengths and weaknesses. The structural model works well if it is properly specified, but does not work well if misspecified in a fairly obvious manner (linear versus log-linear specification). It produces a meaningful estimate of market power and works even in industries with increasing or decreasing returns to scale. Although many structural models have been estimated (apparently) successfully, we had difficulty producing plausible results based on four-digit SIC data.

Based on simulation results, Hall's methods work well when an industry has constant returns. Even slight deviations from constant returns, however, can produce serious biases. The degree of market power based on Hall's estimate of the price/marginal cost markup cannot be determined without additional information. Two advantages of his method is that it is easy to apply and the functional specification is clear. The empirical results based on his methods are sensitive to which of his two approaches are used and to which factors of production are included.

The Panzar-Rosse method is easier to use than the structural model approach. Unfortunately, for many models, it is not possible to distinguish between collusion and competition. The estimate of their key test statistic is sensitive to the specification of the reduced-form revenue function and to which factors of production are included.

## References

Ashenfelter, Orley, and Daniel Sullivan. 1987. "Nonparametric Tests of Market Structure: An Application to the Cigarette Industry." *Journal of Industrial Economics,* 35:483-98.

Berndt, Ernst R., and David O. Wood, "U. S. Manufacturing Output and Factor Input Price and Quantity Series, 1908-1947 and 1947-1981, Massachusetts Institute of Technology, Energy Laboratory Working Paper 86-010WP, January 1986.

Bresnahan, Timothy F. 1982. "The Oligopoly Solution Concept is Identified." *Economics Letters* 10:87-92.

________. 1989. "Studies of Industries with Market Power," in Richard Schmalensee and Robert Willig, eds., *Handbook of Industrial Organization,* New York: North Holland.

Carlton, Dennis W., and Jeffrey M. Perloff. 1994. *Modern Industrial Organization.* New York: HarperCollins Publishing Co. Ed 2.

Domowitz, Ian, Glenn R. Hubbard, and Bruce C. Petersen. 1986. "Business Cycles and the Relationship Between Concentration and Price-Cost Margins." *The Rand Journal of Economics* 17:1-17.

__________. 1988. "Market Structure and Cyclical Fluctuations in U. S. Manufacturing." *Review of Economics and Statistics* 70:55-66.

Hall, Robert E. 1988. "The Relationship Between Price and Marginal Cost in U. S. Industry." *Journal of Political Economy* 96:921-47.

Lau, Lawrence J. 1982. "On Identifying the Degree of Competitiveness from Industry Price and Output Data." *Economics Letters* 10:93-9.

Panzar, John C., and James N. Rosse. 1987. "Testing for 'Monopoly' Equilibrium." *The Journal of Industrial Economics* 35:443-56.

Rosse, James N., and John C. Panzar. 1977. "Chamberlin versus Robinson: An Empirical Test for Monopoly Rents." Studies in Industry Economics, Research Paper no. 77, Stanford University.

Shaffer, S. 1982. "A Nonstructural Test for Competition in Financial Markets." *Proceedings of a Conference on Bank Structure and Competition.* Chicago: Federal Reserve Bank of Chicago.

Shapiro, Matthew. 1987. "Measuring Market Power in U. S. Industry." National Bureau of Economic Research Working Paper no. 2212.

Sullivan, Daniel. 1985. "Testing Hypotheses About Firm Behavior in the Cigarette Industry." *Journal of Political Economy* 93:586-98.

Sumner, Daniel A. 1981. "Measurement of Monopoly Behavior: An Application to the Cigarette Industry." *Journal of Political Economy* 89:1010-19.

## Appendix 1: Linear Model

We now assume that both the demand and the marginal cost curves are linear. The marginal cost curve is

$$MC = \eta + \alpha w + \beta r + \gamma Q + \zeta_C. \tag{A.1}$$

As a result, total costs (ignoring possible fixed costs) are

$$C = [\eta + \alpha w + \beta r + \gamma Q + \zeta_C] Q. \tag{A.2}$$

The factor demands are

$$L = \alpha Q + \zeta_L, \tag{A.3}$$

$$K = \beta Q + \zeta_K. \tag{A.4}$$

The demand curve is

$$p = \phi_0 - [\phi_1 + \phi_2 Z] Q + \zeta_D. \tag{A.5}$$

The slope of the demand curve is $p' \equiv p_Q = -(\phi_1 + \phi_2 Z)$. As a result, the effective marginal revenue is

$$MR(\lambda) = p + \lambda p' Q = p - \lambda[\phi_1 + \phi_2 Z] Q. \tag{A.6}$$

In the equilibrium, $MR(\lambda)$ equals $MC$, so $p = MC + \lambda(\phi_1 + \phi_2 Z) Q$, or

$$p = \eta + \alpha w + \beta r + [\lambda(\phi_1 + \phi_2 Z) + \gamma] Q + \zeta_C + \zeta_D. \tag{A.7}$$

Thus, output demanded is

$$Q = \frac{\phi_0 - \eta - \alpha w - \beta r - \zeta_C}{(\lambda + 1)[\phi_1 + \phi_2 Z] + \gamma}. \tag{A.8}$$

The revenue function is

$$R = \left[\phi_0 + \zeta_D - (\phi_1 + \phi_2 Z)\frac{\phi_0 - \eta - \alpha w - \beta r - \zeta_C}{(\lambda + 1)(\phi_1 + \phi_2 Z) + \gamma}\right] \times \frac{\phi_0 - \eta - \alpha w - \beta r - \zeta_C}{(\lambda + 1)(\phi_1 + \phi_2 Z) + \gamma}. \tag{A.9}$$

That is, even in the linear model, revenue is a complicated, nonlinear function of factor prices and $Z$. It is so ugly that we cannot face writing it out explicitly here. The good news is, however, that, in the linear model, the Panzar-Rosse test statistic $H$ varies with $\lambda$.

## Appendix 2: Data

There are five chief sources of data: (1) productivity data generously provided by Professor Wayne Gray; (2) *Business Statistics*; (3) the *Economic Report of the President*; (4) a data set prepared by the Bureau of Labor Statistics, "Multifactor Productivity in U. S. Manufacturing and in 20 Manufacturing Industries, 1949-86" (April 1989); (5) Economic Statistics Bureau, *Handbook of Basic Economic Statistics*.

All nominal data were deflated using the GNP deflator from (3). Data on money supply (M1), total U. S. population, and crude oil prices are from (3). Military expenditures are from (3) and (5). The series were spliced using the mean of the difference between the two series 1958-63 ($0.8 million was subtracted from the series from (5)). The producer price index for nondurables and for processed foods and farm products are from (3).

The data on the cost of capital, price of materials, and price of energy were from (4). The data on quantity comes from (2). The value of shipments, quantity, and wage data were available at the four-digit SIC level; whereas the cost of capital, price of material, and price of energy were available only at the two-digit SIC level. The value of shipments divided by quantity gives us price. The levels of capital, labor, and material inputs are from (1).

**Table 1**

**Structural Model**

(Percentage of Simulations in which the Hypothesis is Not Rejected)

| | | $\varepsilon_C$ and $\varepsilon_D$ are Distributed: | | |
|---|---|---|---|---|
| | | N(0, 1) | 0.1 N(0, 1) | |
| *Market Structure: True λ* | *Hypothesis λ* | *Cobb-Douglas* | *Cobb-Douglas* | *Linear* |
| Competition | 0 | 98.1 | 95.5 | 83.3 |
| λ=0 | 0.25 | 14.0 | 0 | 81.2 |
| | 1 | 1.8 | 0 | 57.0 |
| Four-Firm Cournot | 0 | .5 | 0 | 100 |
| λ = 0.25 | 0.25 | 95.8 | 94.6 | 100 |
| | 1 | 1.7 | 0 | 100 |
| Collusion | 0 | 0.1 | 0 | 100 |
| λ = 1 | 0.25 | 3.4 | 0 | 100 |
| | 1 | 85.9 | 97.6 | 100 |

**Table 2**

**Hall's Estimation Method**

| *Market Structure True λ* | *Average μ* | *Average p/MC* | *Fail to Reject the Null Hypothesis (%)* Competition N(0,1) | Competition .1N(0,1) | True Model .1N(0,1) |
|---|---|---|---|---|---|
| Competition (λ = 0) | 0.996 | 1.00 | 98.5 | 98.4 | 98.4 |
| Four-Firm Cournot (λ = 0.25) | 1.084 | 1.16 | 98.9 | 12.1 | 90.3 |
| Collusion (λ = 1) | 1.569 | 2.29 | 85.9 | 6.2 | 40.7 |

**Table 3**

**Hall's Instrument Method**

(Percentage of Simulations in which the Competitive Hypothesis is Not Rejected)

| *Market Structure: True λ* | *Instrument Weight ω* | *Corr(I, Δn)* | *Corr(I, θ)* | *% Rejected* |
|---|---|---|---|---|
| Competition | 0.1 | 0.17 | 0.01 | 95.5 |
| λ=0 | 0.5 | 0.84 | 0.01 | 96.5 |
| | 0.9 | 1.0 | 0.01 | 98.0 |
| Four-Firm Cournot | 0.1 | 0.17 | 0.11 | 90.5 |
| λ = 0.25 | 0.5 | 0.84 | 0.48 | 12.5 |
| | 0.9 | 1.0 | 0.56 | 3.0 |
| Collusion | 0.1 | 0.17 | 0.09 | 89.5 |
| λ = 1 | 0.5 | 0.84 | 0.53 | 7.5 |
| | 0.9 | 1.0 | 0.63 | 0.1 |

instrument $\equiv I \equiv \omega \Delta n + (1 - \omega)\zeta$,

$\zeta \sim N(0, 0.1)$,

$\Delta n \equiv \Delta \ln(L/K)$,

$\theta \equiv$ Solow residual

## Table 4

## Empirical Results

| *Industry* (SIC) | *Panzar-Rosse* (*H*, s. e.) | | *Hall Instrument Test* (t-statistic) | | *Hall Estimated Markup* (μ, a. s. e.) |
|---|---|---|---|---|---|
| | *Logarithmic* | *Linear* | *Oil* | *M1* | |
| Red meat | 1.57* | 1.60*# | -0.92 | 0.31 | -0.79# |
| 2011 | 0.38 | 0.41 | | | 0.40 |
| Poultry | 0.60 | 0.42 | -0.09 | 0.45 | 0.77 |
| 2013 | 1.12 | 0.59 | | | 0.62 |
| Butter | 3.46 | 0.21 | 0.47 | 0.63 | 0.58 |
| 2021 | 3.80 | 1.97 | | | 0.31 |
| Cheese | 0.26 | -1.38 | -0.38 | 1.44 | 0.64 |
| 2022 | 0.37 | 0.86 | | | 0.26 |
| Condensed milk | 0.44 | -0.17# | -2.00 | 1.00 | 0.13 |
| 2023 | 0.30 | 0.54 | | | 0.23 |
| Fluid milk | 1.09* | -0.41# | 1.31 | -3.10* | 2.00 |
| 2026 | 0.13 | 0.41 | | | 1.32 |
| Flour | 0.26 | -0.12 | -3.25* | 2.13* | -0.05# |
| 2041 | 0.24 | 0.54 | | | 0.18 |
| Malt Beverage | 0.91* | -0.39*# | -3.75* | 3.00* | 0.19 |
| 2082 | 0.07 | 0.17 | | | 0.34 |
| Wine | 0.59*# | -0.86# | 0.21 | -0.48 | 0.09 |
| 2084 | 0.14 | 0.49 | | | 0.53 |
| Distilled liquor | 0.91*# | -0.91# | -0.40 | -0.05 | 2.70 |
| 2085 | 0.03 | 0.49 | | | 1.07 |
| Cigarettes | 0.52* | 0.37# | -1.75 | 0.48 | 2.47 |
| 2111 | 0.11 | 0.26 | | | 0.77 |
| Cigars | 1.01* | -1.55# | 0.38 | -0.09 | 1.39 |
| 2121 | 0.19 | 0.84 | | | 0.47 |

* - Statistically significantly different from zero at the 5% level based on a two-tail test.
# - Statistically significantly different from one at the 5% level based on a two-tail test.
$\mu \equiv$ price/marginal cost.
$\Delta n \equiv \Delta \ln(L/K)$
$\Delta m \equiv \Delta \ln(M/K)$

**Figure 1: Hall's Estimation Test of Competition when Firms Price Take**

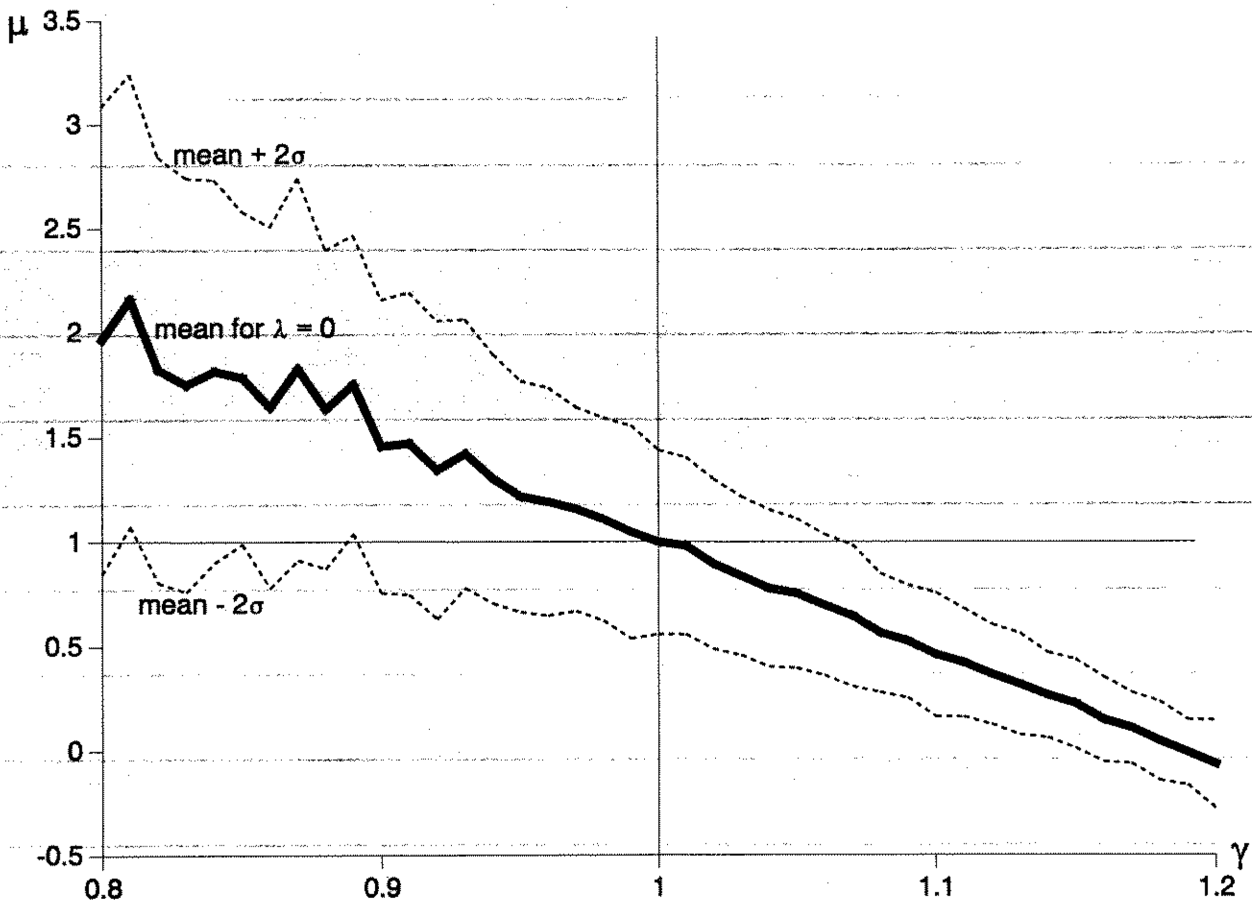

**Figure 2: Hall's Estimation Test of Competition under Three Market Structures**

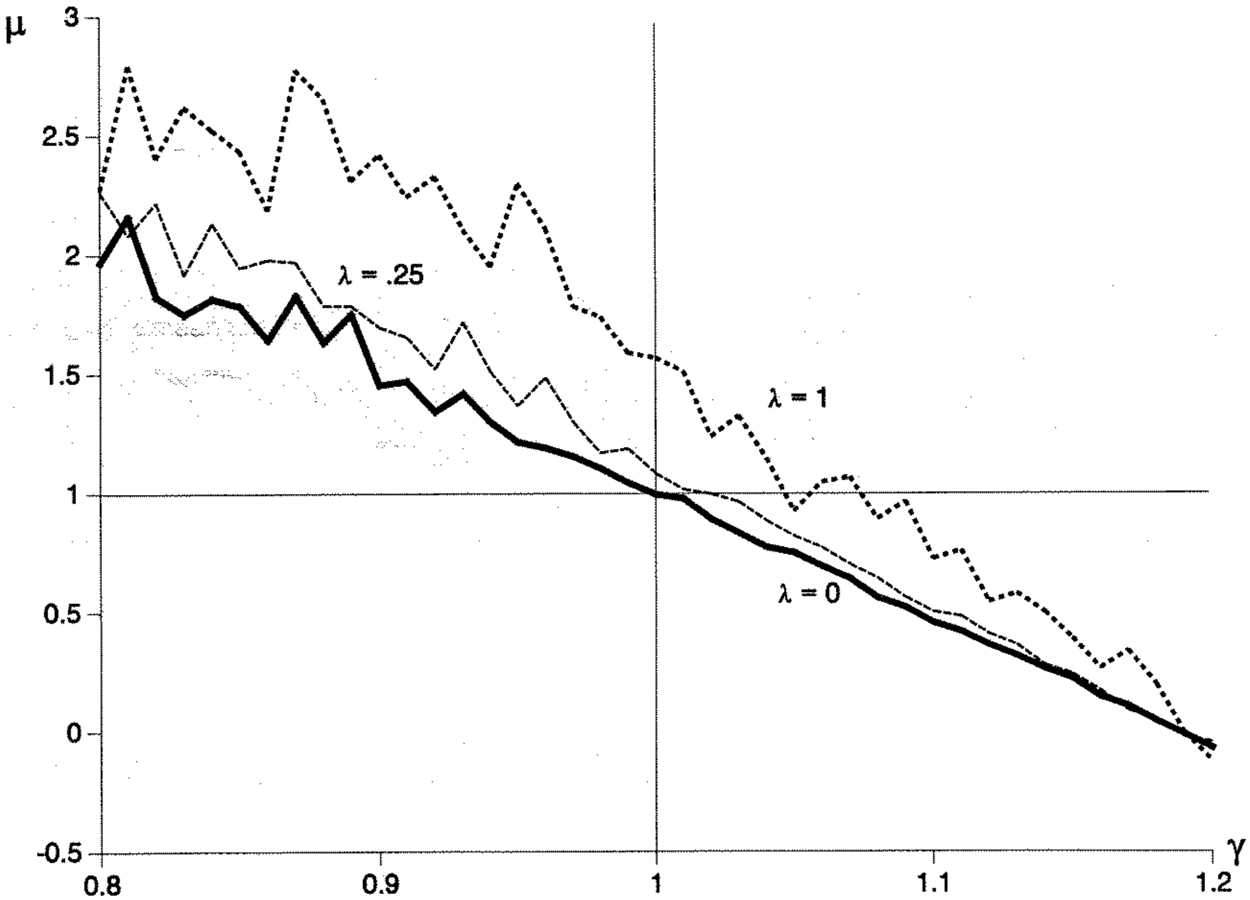

**Figure 3: Hall's Instrument Test of Competition where $\lambda = 0$**