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# *Is there more than one critical concentration ratio? An empirical test for the Portland cement industry*

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Past attempts to estimate the critical concentration ratio maintained the hypothesis of only two structural groupings: competitive versus non-competitive. In view of the spectrum of competitive conduct allowed by oligopoly theory, the validity of the two groupings is restrictive and should be tested. Using data from the Portland cement industry, this paper conducts such a test, employing a non-linear switching regression technique based on the logistic function. The hypothesis of two structural groupings is not rejected.

## I. INTRODUCTION

The concept of a critical concentration ratio (CCR) has received attention from economists in the past. The CCR is defined as the level of concentration beyond which an industry becomes effectively collusive so that profit rates, price–cost margins, and prices rise with concentration. Bain (1951) was the first to observe a dichotomous relationship between rates of return and concentration and found a CCR of 0.7 at the eight-firm level in American manufacturing industry. Others who investigated concentration and performance, and who found a discontinuous relationship stronger than linear, include Meehan and Duchesneau (1973), Rhoades and Cleaver (1973), Dalton and Penn (1976), Geithman *et al*. (1981) and Bradburd and Over (1982).

The approach used by all the foregoing studies, except Bain's original work, was to introduce a dummy variable taking the value one when the concentration ratio is above some critical level and zero below it. This arbitrary dichotomy asserts that, at concentration values greater than the critical level, non-cooperative equilibria are sustainable that closely mirror the monopoly equilibrium. At concentration levels below the critical point, they are not. This implies a sharp transition in market outcomes at the critical point.

A second approach used by White (1976) treated the transition across regimes as a smooth path characterized by a sigmoidal relationship between the measure of concentration and profits (or price), with the inflection point serving as the critical switching point. Using the cumulative normal integral function suggested by Goldfeld and Quandt (1972, pp. 262–64), White (1976) estimated CCR in a sample of 77 US industries.

Although the second approach is superior to the first, insofar as taking the arbitrariness out of CCR estimation, it still shares a common feature – maintenance of the hypothesis of only two structural groupings, competitive versus non-competitive. In view of the spectrum of competitive conduct allowed by oligopoly theory, the validity of the two groupings should be tested.

The purpose of this analysis is to conduct such a test. The method is to use a non-linear switching regression technique employing the logistic function. The logistic function has similar properties as the cumulative normal distribution function used by White, but the logistic function is explicit and simpler to estimate. The point estimate and standard error of the mean of the logistic function indicate, respectively, the value and statistical significance of the switching point between the competitive and non-competitive

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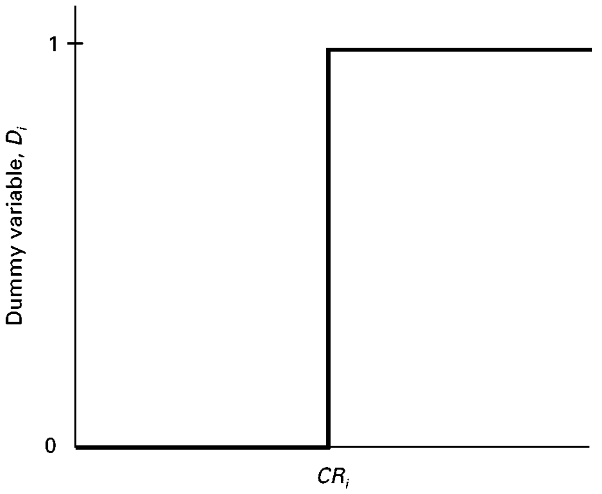


Fig. 1. *A 0–1 dummy variable $D_i$ as a function of $CR_i$*

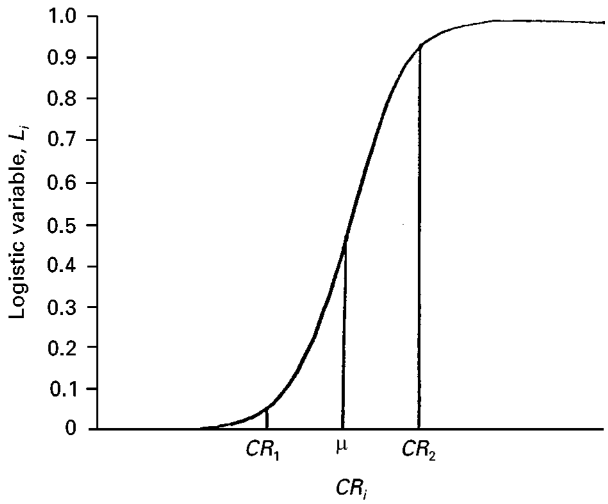


Fig. 2. *A logistic variable $L_i$ ($\mu$, $\sigma$) as a function of $CR_i$; $L_i$ ($\mu$, $\sigma$) = $1/\{1 + \exp[\pi(\mu - CR_i)/\sqrt{3}\sigma]\}$*

regimes. The point estimate and standard error of the variance of the logistic function indicate whether the two groupings are valid, or represent extremes around a third grouping.

The sample data is from the Portland cement industry. Section II provides details of the model. Section III discusses application to the Portland cement industry. Section IV considers variables and sources of data. Section V presents the results and Section VI is the conclusion.

## II. THE MODEL

Traditionally, the estimation of the switching point in dichotomous regression models has taken the following form:

$$P_i = \beta_0 + \alpha D_i + \sum_{j=1}^{k} \beta_j X_{ij} + \varepsilon_i \tag{1}$$

where $P_i$ is the price in the $i$th market, $X_{ij}$ is a set of $k$ structural variables, $\beta_j$ is the vector of parameters to be estimated, and $\varepsilon_i$ is the econometric error term. $D_i$ is a dummy variable which takes the value one when the measure of concentration is greater than a threshold level and zero below it. The above formulation hypothesizes that the competitive and collusive regimes are similar in their price responses to the structural variables represented by the $X_{ij}$'s, but the collusive regime has a higher initial price level represented by a larger intercept. By estimating the above model repeatedly for alternative critical concentration thresholds, one could find the CCR as the level of the concentration ratio which would yield the highest $t$-statistic on the resulting $D_i$ term ($\alpha$) .

A generalization to the above method is to replace the binary dummy variable $D_i$ (Fig. 1) by a cumulative normal integral suggested by Goldfeld and Quandt (1972) and used by White (1976). An improvement in estimation can be achieved, while maintaining the similar properties, by replacing the cumulative normal distribution function with the logistic function (Fig. 2), $L_i(\mu, \sigma)$, resulting in the following generalized dummy variable (GDV) (Doran, 1985):

$$L_i(\mu,\sigma) = \frac{1}{1 + \exp[\pi(\mu - CR_i)/\sqrt{3}\sigma]} \tag{2}$$

where $CR_i$ is the concentration ratio in the $i$th market, and $\mu$ and $\sigma$ and the mean and standard deviation of the distribution, respectively. The replacement of $D_i$ in Equation 1 with $L_i(\mu, \sigma)$ permits the price–cost relationship to follow a nonlinear path (S-curve shape) while still allowing the other structural variables to maintain linear relationships with $P_i$. The new equation takes the form

$$P_i = \beta_0 + L_i(\mu,\sigma) + \sum_{j=1}^{k} \beta_j X_{ij} + \varepsilon_i \tag{3}$$

where $\mu$ and $\sigma$ are unknown parameters. The parameter $\mu$ plays the role of the unknown CCR and $\sigma$ characterizes the smoothness of the distribution.

If $\sigma$ is not statistically different from zero, the logistic approximation reduces to the step function depicted in Fig. 1, supporting a single CCR below which firms compete, and above which firms coordinate (White, 1976, p. 62). Therefore, the competitive–coordinating grouping is valid.

A $\sigma$ that is different from zero would suggest the shape depicted in Fig. 2. It would also imply three structural groupings rather than two. At concentration values less than $CR_1$ (where the GDV is closer to zero), the price concentration relationship is approximately the same and, given such low levels of concentration, the regime is competitive. At concentration values larger than $CR_2$ (where the GDV is closer to one), the price concentration relationship

Table 1. *Descriptive statistics of variables used in the non-linear regression of Equation 4*

| Variable | $N$ | Mean | $S$ | Minimum | Maximum |
|---|---|---|---|---|---|
| Real price of cement ($RPR_{it}$) | 276 | 50.41 | 9.04 | 29.35 | 73.84 |
| Instrument for quantity ($SCLG_{it}$) | 276 | 0.94 | 0.603 | 0.283 | 3.69 |
| Real price of electricity ($RPEL_{it}$) | 276 | 12.997 | 2.707 | 2.721 | 21.24 |
| Real wage rate ($RWAG_{it}$) | 276 | 9.104 | 0.987 | 5.099 | 12.20 |
| Real price of fuel ($RPFU_{it}$) | 276 | 2.084 | 0.406 | 1.165 | 2.97 |
| Average kiln size ($AVSZ_{it}$) | 276 | 321.03 | 125.51 | 135.50 | 654.6 |
| Weighted age of kilns ($WTAG_{it}$) | 276 | 19.79 | 5.606 | 4.59 | 33.19 |
| Percentage capacity using dry technology ($PCDR_{it}$) | 276 | 0.263 | 0.199 | 0.0 | 0.63 |
| Multimarket contacts ($MMC_{it}$) | 276 | 0.287 | 0.077 | 0.155 | 0.61 |
| Herfindahl index ($HERF_{it}$) | 276 | 0.234 | 0.121 | 0.077 | 0.59 |

Note: $N$ is number of observations and $S$ is sample standard deviation.

is also approximately the same and, given such high levels of concentration, the regime is that of an oligopoly with higher coordination. The price–concentration relationship between $CR_1$ and $CR_2$ would reflect continuously increasing levels of coordination. At concentration levels less than $CR_1 = \hat{\mu} - 2.02\hat{\sigma}$, and greater than $CR_2 = \hat{\mu} + 2.02\hat{\sigma}$, the height of the logistic function is less than 0.025 and greater than 0.975, respectively.[1] For all practical purposes, the last two values can be rounded off to a conventional binary dummy variable taking a value of zero for concentration levels below $CR_1$, and a value of one for concentration levels greater than $CR_2$. Hence, two CCRs emerge, $CR_1$ and $CR_2$.

## III. APPLICATION TO PORTLAND CEMENT INDUSTRY

Equation 4 was estimated using data for the Portland cement industry for 25 regional markets over the period 1974–1989.

$$
\begin{aligned}
RPR_{it} = \beta_0 &+ \frac{1}{1+\exp[\pi(\mu - HERF_{it})/\sqrt{3}\sigma]} + \beta_1 SCLG_{it} \\
&+ \beta_2 RPEL_{it} + \beta_3 RWAG_{it} + \beta_4 RPFU_{it} \\
&+ \beta_5 AVSZ_{it} + \beta_6 WTAG_{it} + \beta_7 PCDR_{it} \\
&+ \beta_8 MMC_{it} + \varepsilon_{it} \qquad (4)
\end{aligned}
$$

where $i$ represents a regional cement market, $t$ is a period in time, $RPR_{it}$ is real cement price, $HERF_{it}$ is the capacity based Herfindahl index, $SCLG_{it}$ is the ratio of the predicted value of shipments plus imports to capacity plus imports (an instrument for quantity shipped), $RPEL_{it}$ is real price of electricity, $RWAG_{it}$ is real wage rate, $RPFU_{it}$ is real fuel price, $AVSZ_{it}$ is average kiln size, $WTAG_{it}$ is weighted average kiln age, $PCDR_{it}$ is percentage of capacity using dry

Table 2. *Regional markets included in the analysis*

| | |
|---|---|
| Atlanta | Minneapolis |
| Baltimore | New Orleans |
| Birmingham | New York |
| Boston | Oklahoma City |
| Chicago | Philadelphia |
| Cincinnati | Phoenix |
| Cleveland | Pittsburgh |
| Dallas | St Louis |
| Denver | Salt Lake City |
| Detroit | San Antonio |
| Houston | San Francisco |
| Kansas City | Seattle |
| Los Angeles | |

technology and $MMC_{it}$ is multimarket contacts. Cement shipments plus imports are scaled by capacity to account for diverse capacities across regional markets. An instrument is created for this variable to avoid endogeneity problems. Input prices, $RPEL_{it}$, $RWAG_{it}$ and $RPFU_{it}$, shift the firm marginal cost function and hence the market price of cement. The variables $AVSZ_{it}$, $WTAG_{it}$ and $PCDR_{it}$ are used to account for technological factors. Larger kilns should have lower costs per unit of output. Newer kilns are more energy efficient than older kilns. Kilns using a dry technology should have lower fuel consumption as well. Multimarket contacts could influence individual market prices and is therefore used in the regression equation.[2]

## IV. DATA

The descriptive statistics of variables and markets used for the estimation are presented in Tables 1 and 2, respectively. The following data are computed for each market for each year.

[1] With the cumulative normal distribution function, the coefficient on $\hat{\sigma}$ would be 1.96 rather than 2.02.
[2] See Bernheim and Whintson (1990), Scott (1993) and Rosenbaum and Jans (1993) for details on multimarket contacts.

*Price of cement* ($RPR_{it}$). The *Minerals Yearbook* reports information on value and volume of shipments by Portland cement districts. A measure of transaction price can be obtained by dividing value by volume. A weighted average price is then computed for each regional market for each year by weighing the price in each district by the percentage of the market's production capacity located in that district.

*Instrument for quantity* ($SCLG_{it}$). The *Minerals Yearbook* publishes annual data on cement shipments by volume, and plant capacities, aggregated to Portland cement producing districts. Using this information, a shipment-to-capacity ratio is calculated for each Portland cement district.

The Portland Cement Association (PCA), in its *Plant Information Summary*, annually publishes location, ownership, capacity, age and technology information for practically all cement kilns in the United States. Using this information it is possible to identify all kilns within each regional market and to calculate market kiln capacity.[3]

From the PCA *Plant Information Summary*, it is possible to determine, for each regional market, the percentage of market kiln capacity that lies within each Department of Interior Portland cement district. Using these percentages as weights, a weighted average shipments-to-capacity ratio is calculated for each market from the *Minerals Yearbook* district ratios described above. These market shipment-to-capacity ratios are then multiplied by unadjusted capacities to get an estimate of shipments for each regional market.[4] Import volumes are then added to get an import-adjusted measure of shipments.

To avoid endogeneity problems, an instrument is created for quantity. More than 90% of cement is used in construction. To create the instrument, shipments are regressed on current, once-lagged and twice-lagged highway and non-highway construction expenditures.[5] The expected values are then calculated and used as instruments.

*Herfindahl index* ($HERF_{it}$). The Herfindahl index used in the analysis is a capacity-based index. A Herfindahl index of 0 (1) indicates perfect competition (monopoly).

*Price of electricity* ($RPEL_{it}$). State-level electricity prices for the industrial sector are reported in the *Energy Price and Expenditure Data Report* (US Department of Energy). The state-level data are weighted by corresponding kiln capacities to get metropolitan-level data. The percentage of market capacity located within each state is used as the weight.

*Price of labour* ($RWAG_{it}$). Labour costs data were obtained from *Employment Hours and Earnings*. State-wide average hourly wage for non-supervisory workers in all manufacturing industries was used as the wage rate. These wage rates were weighted by the percentage of market capacity located in each state to obtain metropolitan-area wage rate.

*Price of fuel* ($RPFU_{it}$). State-level prices for coal and natural gas are reported in *Energy Price and Expenditure Data Report*. These prices are weighted by the percentage of market capacity located within each state to get metropolitan-level prices. The *Energy Report* by the Portland Cement Association provides the breakdown of the annual coal and natural gas usage by kilns at the national level. These breakdowns were used to weight the metropolitan-level prices for each type of fuel to compute a fuel price per million BTU.

*Average size* ($AVSZ_{it}$). The average kiln capacity is used as a proxy for economies of scale.

*Age* ($WTAG_{it}$). This measures the weighted average age of kilns in a market in years. The relative capacities were used as weights.

*Percentage of capacity using dry technology* ($PCDR_{it}$). This is computed from capacity data.

*Multimarket contacts* ($MMC_{it}$). Let the subscript $l = 1, \ldots, L$ represent a firm, and $j = 1, \ldots, J$ represent a market. Let $V_{ij}$ be equal to 1 if firm $i$ operates in market $j$, and 0 otherwise. Then construct the $L \times L$ symmetric matrix

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1L} \\ \vdots & \ddots & \vdots \\ a_{L1} & \cdots & a_{LL} \end{bmatrix} \tag{5}$$

where

$$a_{km} = \sum_{j=1}^{J} V_{kj} V_{mj} \tag{6}$$

Off-diagonal elements $a_{km}$ measure the number of times firms $k$ and $m$ meet in various markets, and the diagonal

[3] In some markets, imports increased over the period analysed. Using information from the US Department of Interior *Minerals Yearbook*, it is possible to determine the volume of imports into each regional market in each year. These import volumes are added to capacities to get an import-adjusted measure of capacity.
[4] Unadjusted capacities are capacities before imports are added.
[5] Annual street and highway expenditures for each market are obtained from the Department of Commerce's *City Government Finances*. Non-highway construction expenditures are the sum of new residential and non-residential, non-highway expenditures. Data on current dollar new residential construction expenditures are published in *Housing Authorized by Building Permits and Public Contracts*. Current dollar annual expenditures for non-residential construction activity are published in *The Construction Review*. The two are combined and deflated to real values.

elements measure the number of markets in which each firm operates.

If home market $j$ contains $N_j$ firms, then $N_j(N_j - 1)/2$ enumerates the total number of possible pairings of firms in that home market. One can then define

$$PAIR_j = \sum_{k=1}^{L-1} \sum_{m=k+1}^{L} a_{km} V_{kj} V_{mj} - N_j(N_j - 1)/2 \qquad (7)$$

$PAIR_j$ measures the total number of observed pairings of firms from home market $j$ minus the number of pairings in market $j$ itself. It is the number of non-home market pairings among firms in home market $j$.

Now construct the $L \times L$ symmetric matrix with elements

$$b_{kmj} = \sum_{z \neq j}^{J} V_{kz} V_{mz} (MS_{kz} + MS_{mz}) \qquad (8)$$

where $MS_{kz}$ denotes firm $k$'s market share in market $z$. Off-diagonal elements $b_{kmj}$ aggregate the market shares for firms $k$ and $m$ across all non-home markets in which they meet. Then define

$$MMC_j = \frac{\sum_{k=1}^{L-1} \sum_{m=k+1}^{L} b_{kmj} V_{kj} V_{mj}}{PAIR_j} \qquad (9)$$

where $MMC_j$ is the average market share in non-home markets of all observed firm pairings from market $j$.

Data from yearly issues of the Portland Cement Association's *Plant Information Summary* are used to calculate this measures. To ensure reliability, kilns were tracked from year to year. This allows us to identify changes in ownership and additions and deletions of kilns. The *Minerals Yearbook* also summarizes yearly ownership changes and capacity additions. The PCA data were cross-referenced against the *Minerals Yearbook* data to ensure consistency.

## V. RESULTS

Non-linear regression results of Equation 4 are presented in Table 3. The estimates of $\hat{\mu}$ and $\hat{\sigma}$ are 0.32 with the $t$-statistic of 1.97 and 0.028 with the $t$-statistic of 0.14, respectively. The estimate of $\hat{\mu}$ is significantly different from zero whereas $\hat{\sigma}$ is not. This indicates that the CCR in the Portland cement industry is a Herfindahl index of 0.32, with a confidence interval of 0.0002 and 0.63 at 95% significance level. The results do not support the hypothesis of more than one CCR. This implies the conventional competitive–coordinating grouping is valid, and that the switch from the competitive regime to the collusive regime is abrupt rather than smooth. The proportion of markets in the sample where the Herfindahl index is 0.32 or below is approximately 80%.

Table 3. *Non-linear regression estimates of Equation 4*

| Parameter | Estimated coefficient |
|---|---|
| $\hat{\mu}$ | 0.32[a] |
| | (1.97) |
| $\hat{\sigma}$ | 0.03 |
| | (0.14) |
| $\beta_0$ | 35.47[a] |
| | (4.76) |
| $\beta_1$ | 0.91 |
| | (0.88) |
| $\beta_2$ | − 0.20 |
| | (− 0.91) |
| $\beta_3$ | − 1.12[a] |
| | (− 2.04) |
| $\beta_4$ | 10.90[a] |
| | (8.13) |
| $\beta_5$ | − 0.01[a] |
| | (− 1.67) |
| $\beta_6$ | 0.10 |
| | (0.83) |
| $\beta_7$ | − 6.79[a] |
| | (− 2.34) |
| $\beta_8$ | 28.46[a] |
| | (3.64) |

Notes: Numbers in parentheses are $t$ statistics.
[a] Statistical significance from zero at the 5% level.

The parameter associated with $SCLG_{it}$ is not significant, implying that cement prices are not influenced by the quantity demanded. Cement prices are decreasing in wages. However, this may be due to the correlation within the industry between high wages and productivity. Cement prices are increasing in fuel prices but not influenced by the price of electricity. The coefficient for the $AVSZ_{it}$ is significantly negative, implying that size-related savings allow firms to lower cement prices.

The results also indicate that the weighted average kiln age ($WTAG_{it}$) does not significantly affect cement prices. This may be due to the fact that older kilns become less efficient at retaining heat so they are relined with new tiles and hence become more efficient. Dry technology in cement production consumes less fuel per unit of output. As the percentage of kilns that uses the dry technology increases, production costs decline and consequently lower the market price of cement. The evidence for this is found in the negative coefficient for $PCDR_{it}$.

Multimarket contacts ($MMC_{it}$) is included in the model to capture the effect of firms' contacts across markets on their pricing within markets. The theory asserts that 'when firms meet across multiple markets, the threat of retaliation in *all* markets reinforces collusive pricing in *each* market' (Rosenbaum and Jans, 1993). The results of this study lend support for this assertion, that prices increase when firms meet across multiple concentrated markets. Similar results were obtained by Rosenbaum and Jans (1993).

## VI. CONCLUSIONS

A non-linear switching regression model is applied to a sample of regional markets in the Portland cement industry to test the hypothesis that there can be more than one critical concentration ratio. Also, the model used in the analysis allows for a smooth transition in firm conduct from competition to coordination rather than an abrupt switch characterized by a 0–1 dummy variable. The results indicate that there is only one critical concentration ratio, a Herfindahl index of 0.32 for this sample. Hence the use of a simple dummy variable approach with 0.32 as the cut-off point may be appropriate.

Since the technique used in this paper is simple to implement, researchers no longer need to specify a CCR a *priori*, or search for a CCR using more complicated methods.

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