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Distinguishable Patterns of Competition, Collusion, and Parallel Action

by

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Abstract

Alternative market structures are distinguishable by the degree of parallel action exhibited by producers. We show that the correlation between output levels varies systematically with the degree of interdependence among firms, and establish an ordering among alternative behavioral hypotheses (Cournot, Stackelberg, Edgeworth/Bertrand, collusion, and perfect competition). Because the ordering is invariant to the values of background parameters, statistical tests of market conduct may be possible even when the slopes of the demand curve and marginal cost curves are unknown. An application to the world oil market finds strong evidence of collusive behavior among OPEC members, but not elsewhere. (JEL: D43, L11, L13, Q41)

Keywords: cartels, collusive behavior, interdependence, oligopoly, OPEC.

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I. Introduction

Parallel action is widely regarded as an ambiguous indicator of collusive behavior. The divergent antitrust implications of parallel price movements, which may be exhibited either by perfectly competitive firms or members of a cartel, illustrate a general problem that confronts empirical research into market structure and conduct. To a certain degree, the guiding force of market equilibrium tends to align the observed behavior of all types of profit-maximizing firms and create the appearance of concerted action, whether by deliberate design or unavoidable happenstance. Any diagnosis of market conduct based primarily on parallel action must therefore be rooted in an analytical framework that distinguishes among closely related phenomena. This paper contributes to that framework by relating the predicted scope of parallel output changes to the underlying degree of mutual interdependence among firms.

Many previous papers have grappled with parallelism in one way or another. Potiowsky, Smith, and Vaughn (1988) and Howard and Stanbury (1990) point to the broad similarity of perfectly competitive and collusive forms of behavior and emphasize the difficulty of identifying characteristic differences. Areeda (1986) emphasizes the need to look for "unnatural parallelism," i.e., those instances in which the observed parallel action would probably not have resulted from "chance, independent responses to common stimuli, or mere interdependence unaided by an advance understanding among the parties." Baker (1993) cites the evidentiary value of "parallelism plus," meaning that something indicative of a secret agreement must be demonstrated beyond the mere fact of parallel action.

Bresnahan's summary (1989) of what has been called the "New Empirical Industrial Economics" outlines a general approach for mapping hypothesized degrees of producer interdependence into telltale signs that would show up in comparative static adjustments to various kinds of shocks to the operating environment of the industry and/or firm in question. Indeed, Bresnahan's outline serves as a blueprint for a wide array of studies that have attempted to infer the degree of competitive behavior in one industry or another. However, since the predicted magnitude of comparative static adjustments typically depends on parameters like the slope of the demand curve, as well as on the degree of mutual interdependence among firms, these procedures may in practice constitute a joint test of several hypotheses—one maintained and others unspecified. Harstad and Phlips (1994) and Phlips (1996) highlight the confounding influence of these unobservable parameters in their demonstration of the "indistinguishability" of multi-plant monopoly and perfect competition.

The rather extensive literature on "conscious parallelism," including the contributions by MacLeod (1985), Normann (2000), and others, muddies the waters further by demonstrating that oligopolistic rivals who share "mere interdependence" might follow dynamic strategies that emulate the behavior of a deliberate cartel. There is also the question of whether the behavior of a cartel hobbled by imperfect enforcement mechanisms might be indistinguishable from that of a group of producers who are merely interdependent, as in Cubbin (1983).

A few studies are particularly relevant to the issues of parallelism and distinguishability raised here. Doyle and Snyder (1999), who expand on earlier work by Li (1985), suggest that industry-wide demand shocks tend, *ceteris paribus*, to increase parallelism (measured by the correlation among observed output changes), whereas idiosyncratic cost shocks tend to decrease parallelism among interdependent firms. On that basis, and taking into account the extent to which signals of demand and cost shocks are communicated to all producers, they are able to fashion tests that confirm the existence of interdependent behavior among firms in their sample (U.S. automobile producers). Their tests are limited, however, to the hypothesis that some degree of interdependence does exist; they do not differentiate among various levels of interdependence (e.g., Cournot versus cartel behavior).

The Doyle-Snyder approach, which is based on output effects, contrasts with Panzar and Rosse (1987), who also focus on the reaction of interdependent firms to cost shocks, but devise a non-parametric test based on revenue effects. For a firm with no strategic interaction with rivals, revenue must fall if all factor prices rise in proportion. Thus, the Panzar-Rosse test hinges on the sign of the revenue elasticity of factor prices. Like Doyle and Snyder, this test can give ambiguous results since perfectly competitive firms and monopolists are alike in facing no strategic interaction. Moreover, as the authors demonstrate, even some firms that do face strategic interaction might not respond differently, so the power of the test may be low. Sullivan (1985) and Ashenfelter and Sullivan (1987) extend the Panzar-Rosse analysis of comparative static adjustment to cost shocks to place a lower bound on the “equivalent” number of Cournot firms and/or the conjectural variations parameter.

We follow along the path of these earlier studies by examining rivals' comparative static output adjustments to idiosyncratic (independent) cost shocks. Not only does the influence of such cost shocks reduce the correlation among rivals' output changes, as Doyle and Snyder (1999) and Li (1985) have argued, but also the magnitude of that reduction is a reflection of the degree of interdependence. A Stackelberg leader, for example, takes greater advantage of rivals' cost shocks than Cournot producers would do; and the manager of a cartel takes greater advantage still. Thus, at least for the producers of a homogeneous product, it is possible to establish benchmarks and rank alternative behavioral hypotheses by the predicted degree of parallelism in output levels. Because the ranking depends only on the degree of interdependence, not underlying structural parameters like slopes of demand or marginal cost curves, the analysis is not so easily confounded by uncertainty regarding these background parameters.

To adapt Areeda's terminology, the degree of "natural parallelism" in output levels can be shown to vary systematically across market models. In situations where it is possible to control for variations due to common demand shocks, as in the OPEC application reported later in this paper, this approach may allow the observer to distinguish mere interdependence from collusive and perfectly competitive behavior on the basis of the observed degree of parallel behavior among producers.

The intrinsic link between interdependence and parallel action is examined in Section II. Specific hypotheses regarding the traditional models of oligopolistic and collusive behavior are developed further in Section III. The application to OPEC is discussed in Section IV. The main contribution of the paper is summarized in the concluding section V.

II. Output Correlations Induced by Cost Shocks

Imagine an industry consisting of N firms, each of which produces a homogeneous product subject to marginal cost:

$$mc_i(q_i) = a_i + b_i q_i, \tag{1}$$

where mc_i represents marginal cost of the i^{th} firm and q_i its output level, with $a_i > 0, b_i > 0$. We allow the a_i to vary randomly from period to period. Specifically, we assume $E[\Delta a_i] = 0$ and $E[\Delta a_i^2] = \sigma^2$ for all i, and also $E[\Delta a_i \Delta a_j] = 0$ for all $j \neq i$. Variations in the a_i represent idiosyncratic shocks to the marginal cost functions of the several producers.

Market demand for the combined output of all producers is represented by the linear demand function:

$$Q_d(p) = D - p, \tag{2}$$

where without loss of generality we have measured output in units such that the slope of the demand curve is –1.

Under various assumptions regarding the degree of interdependence among the N firms, we will examine the reduced form specification of equilibrium output for each firm. In particular, we seek to measure the extent to which comparative static output adjustments to the hypothesized cost shocks are correlated among producers.

The Perfectly Competitive Benchmark

If all producers take price as given, the first-order conditions for profit maximization require:

$$q_i(p) = (p - a_i)/b_i. \tag{3}$$

To simplify matters, we assume at present that all b_i are identical, although this is not necessary for the results that follow. The total quantity supplied would then vary with price as:

$$Q_s(p) \quad = \quad \sum_{i=1}^{N} q_i(p) \quad = \quad \sum_{i=1}^{N} \frac{p-a_i}{b} \quad = \quad \frac{Np}{b} - \frac{1}{b}\sum_{i=1}^{N} a_i \,. \qquad (4)$$

Equating demand with supply yields the equilibrium price:

$$p^* \quad = \quad \frac{bD + \sum_{i=1}^{N} a_i}{b+N}\,. \qquad (5)$$

Substituting this expression into the first-order conditions determines the output of each producer:

$$q_i \quad = \quad \frac{bD - (b+N-1)\,a_i + \sum_{j\neq i} a_j}{b(b+N)}\,. \qquad (6)$$

Equation (6) represents the reduced form, wherein equilibrium output levels are expressed solely in terms of exogenous variables. Holding demand constant, the adjustments to outputs pursuant to any set of cost shocks is found by differencing:

$$\Delta q_i \quad = \quad -\frac{b+N-1}{b(b+N)}\Delta a_i + \frac{1}{b(b+N)}\sum_{j\neq i}\Delta a_j \,. \qquad (7)$$

Noting that E[Δq_i] = 0 for all i, it is then straightforward to evaluate the covariance of output adjustments for any two producers:

$$\mathrm{E}[\Delta q_i \Delta q_j] \quad = \quad -\sigma^2\left[\frac{2(b+N-1)}{b^2(b+N)^2} - \frac{N-2}{b^2(b+N)^2}\right] \quad = \quad -\sigma^2\,\frac{(2b+N)}{b^2(b+N)^2}\,, \qquad (8)$$

where all cross-products of the form E[$\Delta a_i \Delta a_j$] vanish. The variance of each producer's own output adjustment is computed similarly:

$$\mathrm{E}[\Delta q_i^2] = \sigma^2\left[\frac{(b+N-1)^2+(N-1)}{b^2(b+N)^2}\right]. \tag{9}$$

The correlation between output adjustments of perfectly competitive producers is then:

$$\rho_{perfcomp} = \frac{E[\Delta q_i \Delta q_j]}{\sqrt{E(\Delta q_i^2)E(\Delta q_j^2)}} = -\frac{2b+N}{(b+N-1)^2+(N-1)}, \tag{10}$$

which is of order *1/N* and therefore goes to zero as the number of producers grows. Thus, the perfectly competitive benchmark implies zero correlation among the output adjustments that emanate from idiosyncratic cost shocks.

If we assume further that output adjustments are distributed normally, then the competitive benchmark can also be stated in terms of the probability of compensating output adjustments. Compensating changes are the opposite of parallel action: an increase in output by one producer that offsets the decline of another. Such behavior arises for various reasons, and with varied frequency, depending on the degree of interdependence among firms. In the perfectly competitive case, where the degree of interdependence is zero, compensating output changes would occur only by chance and with a frequency of 50%. This may be confirmed as follows:

$$\begin{aligned}\theta_{perfcomp} &= \Pr[\Delta q_i \Delta q_j < 0] \\ &= \Pr[(\Delta q_i < 0 \cap \Delta q_j > 0)] + \Pr[(\Delta q_i > 0 \cap \Delta q_j < 0)] \\ &= \Pr[\Delta q_i < 0]\Pr[\Delta q_j > 0] + \Pr[\Delta q_i > 0]\Pr[\Delta q_j < 0] \\ &= \tfrac{1}{2} \times \tfrac{1}{2} + \tfrac{1}{2} \times \tfrac{1}{2} = \tfrac{1}{2}, \end{aligned} \tag{11}$$

where the third equality relies on independence, and the fourth relies on symmetry.

In summary, there should be no correlation among the individual reactions of perfectly competitive firms to idiosyncratic cost shocks. In addition, if shocks are distributed normally, then compensating output changes among perfectly competitive producers should occur with a frequency of 50%. These results are independent of the slope of the demand curve and the slopes of individual marginal cost curves.

Parallelism Among Interdependent Producers

The reduced form of output adjustments for any linear model involving N producers can be written in the form:

$$\Delta q_i \quad = \quad -w_{ii}\Delta a_i + \sum_{j\neq i} w_{ij}\Delta a_j \text{ , for } i = 1, \ldots, N; \tag{12}$$

where the weights $\{w_{ij}\}$ attached to respective cost shocks reflect the degree of interdependence among producers (cf. Equation 7), and the specification of cost shocks remains as before. As w_{ij} increases relative to w_{ii}, for example, variation in the level of producer *j's* marginal cost exerts a larger influence on the output of producer *i*. We show in the next section that many common market models are nested within this general specification (e.g., Cournot, Stackelberg, cartel, etc.).

To avoid undue complexity, we examine the special case in which there are only two producers, but the nature of our results is not thought to be affected by this simplification.[1] Thus, the reduced form can be written:

$$\begin{aligned} \Delta q_1 \quad &= \quad -w_{11}\Delta a_1 + w_{12}\Delta a_2, \\ \Delta q_2 \quad &= \quad +w_{21}\Delta a_1 - w_{22}\Delta a_2; \end{aligned} \tag{13}$$

where the w_{ii} measure the direct effects of cost shocks, and the w_{ij} ($i \neq j$) measure the indirect effects. It is easy to confirm that the variance of each producer's own output change is:

$$\mathrm{E}[\Delta q_i^2] \quad = \quad \left(w_{i1}^2 + w_{i2}^2\right)\sigma^2, \qquad \text{for } i = 1, 2;$$

and the covariance between producers is:

$$\mathrm{E}[\Delta q_1 \Delta q_2] \quad = \quad -\left(w_{11}w_{21} + w_{12}w_{22}\right)\sigma^2 .$$

The correlation between output adjustments of the two producers is therefore given by:

$$\begin{aligned} \rho \quad &= \quad - \frac{w_{11}w_{21} + w_{12}w_{22}}{\sqrt{w_{11}^2 + w_{12}^2}\sqrt{w_{21}^2 + w_{22}^2}} \\ &= \quad - \frac{\lambda_1 + \lambda_2}{\sqrt{1+\lambda_1^2}\sqrt{1+\lambda_2^2}}; \end{aligned} \tag{14}$$

where $\lambda_1 = w_{12}/w_{11}$ *and* $\lambda_2 = w_{21}/w_{22}$. The (λ_i) are significant because they measure the degree of interdependence among producers.[2] Equation 14 then demonstrates that the correlation among output levels depends only upon the degree of interdependence among firms. Because the numerator of Equation 14 is strictly positive unless both w_{12} *and* w_{21} are zero, any degree of interdependence among producers will impart some negative correlation to their output adjustments. That correlation is strictly decreasing in the degree of interdependence and therefore provides an unambiguous behavioral index.

Taking the derivative of ρ with respect to λ_i, we have:

$$\frac{\partial \rho}{\partial \lambda_i} \quad = \quad - \frac{1 - \lambda_1\lambda_2}{\left(1+\lambda_i^2\right)\sqrt{1+\lambda_1^2}\sqrt{1+\lambda_2^2}} \qquad (\text{for } i = 1, 2). \tag{15}$$

Thus, any increase in the degree of interdependence among producers will cause output

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[1] A formal extension to the case where N>2 is beyond the scope of this paper.

[2] Further simplification is possible in fully symmetric models where the degree of interdependence is uniform across firms: $\rho = -2\lambda/(1+\lambda^2)$. The more general specification, as in Equation 14, admits leader-follower models and other types of asymmetric equilibria, as well.

adjustments to be more negatively correlated, at least for $\lambda_1\lambda_2 < 1$ (which is the relevant range, as we will see in the next section).

This is a key result that deserves some emphasis: in terms of output levels, the extent of parallel action *decreases* as the degree of interdependence rises. The notion that colluding firms might exhibit parallel *price movements* (as perfectly competitive firms might also do), should not obscure the fact that, in terms of *output levels*, colluding firms should exhibit *less* parallel behavior than either perfectly competitive firms or Cournot firms.

The probability of compensating output changes is given by:

$$\theta \quad = \quad \Pr[\Delta q_1 < 0 \cap \Delta q_2 > 0] \; + \; \Pr[\Delta q_1 > 0 \cap \Delta q_2 < 0]. \tag{16}$$

Both terms can be treated similarly, so we focus only on the first. After substituting for the Δq_i from Equation 13, the first term becomes:

$$\begin{aligned} \Pr[\Delta q_1 < 0 \cap \Delta q_2 > 0] \quad &= \quad \Pr[(-w_{11}\Delta a_1 + w_{12}\Delta a_2 < 0) \cap (w_{21}\Delta a_1 - w_{22}\Delta a_2 > 0)] \\ &= \quad \Pr[(\Delta a_1 > \lambda_1 \Delta a_2) \cap (\Delta a_2 < \lambda_2 \Delta a_2)]. \end{aligned} \tag{17}$$

Joint realizations of Δa_1 and Δa_2 that satisfy the first inequality fall in the horizontally shaded portion of Figure 1; realizations that satisfy the second inequality fall in the vertically shaded portion. The intersection of the two is divided into three sections, S_1, S_2, and S_3. The probability of a realization falling into S_2 (i.e. $\Pr[\Delta a_1 > 0 \cap \Delta a_2 < 0]$) is fixed at 25% (due to symmetry and independence of the underlying distributions) and independent of the values of the λ_i. Unless both λ_1 and λ_2 equal zero (i.e., no interdependence), the probabilities associated with S_1 and S_3 will be strictly positive (since the distributions of shocks are non-degenerate). Moreover, it is clear from Figure

1 that the sizes of S_1 and S_2 are increasing in λ_2 and λ_1, respectively. Thus, the probability of compensating output changes must exceed 50% (taking account of both terms in Equation 16), and must rise with any increase in the degree of interdependence among producers.

III. Models of Interdependent Behavior

Here we briefly examine a few of the standard models of oligopoly behavior. Of primary interest is the comparative degree of interdependence among models, as measured by the λ_i, and resulting implications regarding the degree of parallel behavior among producers.

Frictionless Cartel

By "frictionless cartel" cartel, we mean essentially a multi-plant monopoly that attempts to maximize total profit. Output is shuffled among plants whenever idiosyncratic cost shocks create opportunities to enhance total profit by expanding or contracting output here and there. This process of reallocation leads to a greater probability of compensating output changes than perfectly competitive producers would exhibit, and less parallel behavior.

The reason is simple. Holding all else equal, when two perfectly competitive producers both experience positive cost shocks, both will reduce their output levels—creating parallel action. Compensating output changes arise for competitive producers only when their cost shocks are in *opposite* directions. Cartel members, however, will exhibit compensating production changes even on some occasions when their cost shocks are in the same direction. For example, if all members experience upward shocks, the cartel's marginal cost curve will rise and total output must fall, which means that marginal revenue will be higher at the new optimum. But if one member experienced only a small shock, (i.e., a minor upward shift to its marginal cost curve), then not only will its *share* of total cartel output rise, but in order for its marginal cost to reach the new (higher) marginal revenue target, it may have to increase production. Although its costs have risen, they have fallen relative to others in the cartel.[3] Thus, circumstances that would produce *parallel* actions by competitive firms will sometimes produce *offsetting* actions by members of the cartel. The frequency of compensating output changes among members of a frictionless cartel is therefore higher than for perfectly competitive producers. These ideas are formalized in the following model.

Let the i^{th} producer's marginal cost function be given by $mc_i(q_i) = a_i + b_i q_i$, as in Equation 1. The cartel manager determines individual output levels such that marginal cost from each producer is equal to the marginal revenue of additional sales:

$$mc_i = a_i + b_i q_i = D - 2q_1 - 2q_2 \qquad \text{for } i = 1, 2.$$

This yields the optimal output levels:

$$q_i = \frac{b_2 D + 2a_j - \left(2 + b_j\right) a_i}{k_1}, \qquad \text{for } i = 1, 2; \tag{18}$$

where for convenience we define $k_1 = 2b_1 + 2b_2 + b_1 b_2$. Output changes are then obtained by taking differences in the reduced form:

$$\Delta q_1 = -\frac{2 + b_2}{k_1}\Delta a_1 + \frac{2}{k_1}\Delta a_2 \qquad \text{and} \qquad \Delta q_2 = \frac{2}{k_1}\Delta a_1 - \frac{2 + b_1}{k_1}\Delta a_2. \tag{19}$$

In terms of interdependence, we have:

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[3] Levin (1985, 1988) explores similar implications of output reallocations among oligopolists.

$$\lambda_1^{cartel} \quad = \quad \frac{2}{2+b_2} \qquad \text{and} \qquad \lambda_2^{cartel} \quad = \quad \frac{2}{2+b_1}.$$

Cournot

Subject to the Cournot conjecture, marginal revenue of the i^{th} producer is given by $mr_i(q_i) = D - q_j - 2q_i$. First-order conditions determine the i^{th} producer's reaction function: $q_i(q_j) = (D-q_j-a_i)/(2+b_i)$, for i = 1, 2, and simultaneous solution then yields the equilibrium output level of each producer:

$$q_i \quad = \quad \frac{(D-a_i)(2+b_j)-(D-a_j)}{k_2}, \qquad \text{for } i = 1, 2; \tag{20}$$

where for convenience we define $k_2 = (2+b_1)(2+b_2)-1$.

The firms' comparative static reactions to idiosyncratic cost shocks are obtained by differencing.

$$\Delta q_i = -\frac{2+b_j}{k_2}\Delta a_i + \frac{1}{k_2}\Delta a_j, \qquad \text{for } i = 1, 2; \tag{21}$$

In terms of interdependence, we have:

$$\lambda_1^{cournot} \quad = \quad \frac{1}{2+b_2} \qquad \text{and} \qquad \lambda_2^{cournot} \quad = \quad \frac{1}{2+b_1}.$$

Stackelberg:

The Stackelberg model is the dominant-firm variant of the Cournot hypothesis in which one firm acts as the "leader" and sets its output in correct anticipation of the reaction of the "fringe." The only change to the Cournot derivation is that the first producer (the leader), after taking into account his rival's reaction function, now has marginal revenue:

$$mr_1 = \frac{D(1+b_2)+a_2-2(1+b_2)\,q_1}{2+b_2}.$$

It is straightforward to confirm that equilibrium levels of output are now given by:

$$q_1 = \frac{D(1+b_2)+a_2-a_1(2+b_2)}{k_3},$$

$$q_2 = \frac{k_3(D-a_2)-D(1+b_2)-a_2+a_1(2+b_2)}{k_3(2+b_2)},$$

where for convenience we define $k_3 = 2 + 2b_1 + 2b_2 + b_1b_2$. Output changes are then obtained by differencing:

$$\Delta q_1 = -\frac{2+b_2}{k_3}\Delta a_1 + \frac{1}{k_3}\Delta a_2 \qquad \text{and} \qquad \Delta q_2 = \frac{1}{k_3}\Delta a_1 - \frac{1+k_3}{(2+b_2)k_3}\Delta a_2 .$$

In terms of interdependence, we have:

$$\lambda_1^{stackelberg} = \frac{1}{2+b_2} \qquad \text{and} \qquad \lambda_2^{stackelberg} = \frac{2+b_2}{1+k_3}.$$

Bertrand-Edgeworth

We reference Dixon's (1992) model of Bertrand-Edgeworth competition, which generalizes Edgeworth's trading process and ensures the existence of an equilibrium in pure strategies. Although each producer acts as a price-setter, the equilibrium necessarily yields the competitive outcome. Output levels are found by equating marginal cost to price for each producer: $a_i + b_iq_i = D - q_i - q_j$, for $i = 1, 2$; and solving simultaneously. It is easy to confirm that the equilibrium is characterized by:

$$q_1 = \frac{Db_2 - a_1(1_1+b_2)+a_2}{k_4},$$

$$q_2 = \frac{Db_1 - a_2(1+b_1) + a_1}{k_4};$$

where for convenience we define $k_4 = b_1+b_2+b_1b_2$. Output changes are then obtained by differencing:

$$\Delta q_1 = -\frac{1+b_2}{k_4}\Delta a_1 + \frac{1}{k_4}\Delta a_2, \qquad \text{and} \qquad \Delta q_2 = \frac{1}{k_4}\Delta a_1 - \frac{1+b_1}{k_4}\Delta a_2.$$

In terms of interdependence, this gives:

$$\lambda_1^{be} = \frac{1}{1+b_2} \qquad \text{and} \qquad \lambda_2^{be} = \frac{1}{1+b_1}.$$

Testable Hypotheses:

The models we have considered thus far are strictly ordered in terms of interdependence among firms. They are also strictly ordered, which is to say potentially distinguishable, in terms of the degree of parallel behavior in response to idiosyncratic cost shocks. Specifically, we have established the following. In terms of the correlation (ρ) among output adjustments:

$$\rho_{cartel} < \rho_{be} < \rho_{stackelberg} < \rho_{cournot} < \rho_{perfcomp} = 0.$$

In terms of the probability (θ) of compensating output adjustments:

$$\theta_{cartel} > \theta_{be} > \theta_{stackelberg} > \theta_{cournot} > \theta_{perfcomp} = 50\%.$$

To confirm this ranking, it is sufficient to gather earlier results and compare the λ_i for respective models.

	Cartel		Bertrand/ Edgeworth		Stackelberg		Cournot
λ_1:	$\frac{2}{2+b_2}$	>	$\frac{1}{1+b_2}$	>	$\frac{1}{2+b_2}$	=	$\frac{1}{2+b_2}$

$$\lambda_2: \quad \frac{2}{2+b_1} \quad > \quad \frac{1}{1+b_1} \quad > \quad \frac{2+b_2}{1+k_3} \quad > \quad \frac{1}{2+b_1}$$

The comparisons in the first row (λ_1) are obvious. The inequalities in the second row can be confirmed by noting that $1+k_3 = (2+b_1)(2+b_2) - 1$.

In addition to these implications of the traditional models of interdependent behavior, we add one further, perhaps more realistic, model of collusive conduct. In contrast to the frictionless cartel, we envision a collusive syndicate of producers who operate under the weight of transactions costs, i.e., a "bureaucratic cartel." In this model, any difficulty in reaching consensus on proposed output revisions (and the profit redistributions that would result) is treated as an added cost. Such transaction costs could easily outweigh whatever benefits would otherwise be achieved via output reallocation unless the scope of the proposed reallocation is substantial and expected to persist. Moreover, the cost of reaching consensus is likely to be higher when the proposed adjustments are in offsetting directions rather than in parallel.

In consequence, the bureaucratic cartel would be expected to review output allocations, and perhaps change them, rather infrequently. Many temporary shocks that might cause members of a frictionless cartel to adjust production levels would rightfully be ignored until they accumulate to a degree that justifies the cost of taking a cooperative decision to revise the status quo. Compensating adjustments, especially, would tend to be suppressed due to the higher transaction costs they entail. The rational result would be a production record in which output changes would be more highly correlated, and compensating output changes less prevalent, than in the case of a frictionless cartel.

To the previous results, we must then add:

$$\rho_{cartel} < \rho_{bureaucracy} \quad \text{and} \quad \theta_{cartel} > \theta_{bureaucracy}.$$

Where the production record of the bureaucratic cartel might rank relative to the other forms of market conduct we have examined depends on the magnitude of transaction costs. If such costs are sufficiently large, it is possible that we could observe:

$$\rho_{bureaucracy} > 0 \qquad \text{and} \qquad \theta_{bureaucracy} < 50\% .$$

In other words, the bureaucratic cartel is the only form of interdependent behavior reviewed here that could conceivably fall on the "other side" of the perfectly competitive benchmark.

IV. Do OPEC Members Collude?

OPEC is often cited as a conspicuous example of that rarest of species: an enduringly successful cartel. On the surface, there seems little to argue. Many would view OPEC's actions over the past thirty years as *prima facie* evidence of collusive behavior. The public record includes regularly scheduled meetings to discuss price targets, a formal quota system (since 1982) with production allocations to each member, and persistently large unused production capacity, at least on the part of a few members. On the other hand, it is well known that many, if not most, OPEC members frequently exceed their allotted quotas, and that frictions among members have at various times caused even the appearance of coordination to break down (e.g., the Iran-Iraq war, the so-called two-tier pricing mechanism in 1977, the Saudi net-back pricing initiative of 1986, the Iraqi invasion of Kuwait in 1990). The tendency of commentators to distinguish between the "cartel core" (which in some cases amounts to only Saudi Arabia) and the "cartel fringe" raises further questions about which members, if any, have engaged in collusive behavior.

Given these ambiguities, one may look to statistical analyses of OPEC behavior for clarification. Unfortunately, however, previous empirical studies of OPEC behavior have been largely inconclusive on the question of collusive behavior. Smith (2003) reviews many earlier attempts to test the competitive and collusive hypotheses, but finds few rejections of either the competitive model or its collusive alternative. Residual uncertainty regarding parameters of the underlying demand and cost functions, compounded by the inherently low power of the tests employed, has thus far defied a broadly based effort to characterize OPEC's behavioral tendencies.

There is nominal evidence to suggest that, if OPEC does act collusively, then it must be of the type that we have labeled a "bureaucratic cartel." OPEC production quotas are reviewed infrequently and changed only if relatively large shocks have disturbed the market during the interim. Throughout the twenty years during which OPEC has assigned individual quotas to each member, revisions have occurred less than twice per year, on average.[4] There are other indications as well that OPEC sometimes puts off the process of revising quotas even after the perceived benefits to the organization have become widely apparent.[5] This is a justifiable policy, of course, if the costs of adjustment threaten to outweigh the benefits.

The propositions developed above regarding parallel action provide a means for further analysis of OPEC behavior. Specifically, we advance the following two hypotheses:

H_1: Output changes among OPEC members are no more highly correlated than output changes among non-OPEC producers.

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[4] Revisions have occurred on average every 7.6 months, although the interval is highly variable. Source: pre-1984, Claes (2001, Table 7.6); 1984-2002, *Oil and Gas Journal* Energy Database.

[5] See, for example, "OPEC Sits Tight Among Market-Share Thieves," *Petroleum Intelligence Weekly*, page 1, July 1, 2002.

H_2: Compensating output changes are no less likely among OPEC members than among non-OPEC producers.

Non-OPEC producers are presumed to behave as competitive producers. Thus, the degree of parallel action among non-OPEC producers establishes the competitive benchmark. Under all but one of the alternative hypotheses we have considered (frictionless cartel, Cournot, Stackelberg, and Bertrand), even less parallel action would be expected than under the competitive case. Thus, rejection of H_1 and H_2 would constitute rejection of those forms of interdependent behavior as well, and leave the "bureaucratic cartel" hypothesis as the only mode of behavior consistent with the data.

Data:

The data consist of the monthly crude oil production series compiled by the US Energy Information Administration and published in the *International Petroleum Monthly* (2002). These series cover each of the eleven current OPEC member countries, plus eight non-OPEC producers.[6] The data represent EIA's melding of production reports originally published by *Petroleum Intelligence Weekly* and the *Oil and Gas Journal*. They deviate significantly in many instances from the self-reported (and perhaps self-serving) production figures published by the individual OPEC members. Each series extends from January 1973 through December 2001, giving 348 monthly observations on each country's output level.

Output changes are measured as follows:

$$\Delta q_i^t = q_i^t - q_i^{t-1}$$

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[6] The set of non-OPEC producers (Canada, China, Egypt, Mexico, Norway, Russia, United Kingdom, and United States) includes all non-OPEC producers for which EIA production records are available for the entire sample period.

where *"i"* designates a specific producer or group of producers and *"t"* designates the month for which production is reported. The correlation of output changes for any two producers over the sample period is then given by:

$$\hat{\rho}_{ij} = \frac{\operatorname{cov}(\Delta q_i, \Delta q_j)}{sd(\Delta q_i)sd(\Delta q_j)}.$$

Producer i is counted as having exhibited a compensating change vs. producer j in any month for which: $\Delta q_i^t \times \Delta q_j^t < 0$. The relative frequency of compensating production changes over the interval from T_1 to T_2 can then be represented as f_{ij}:

$$f_{ij} \;=\; \sum_{t=T_1+1}^{T_2} I_{ij}^t \Big/ (T_2 - T_1),$$

where I_{ij}^t is an indicator variable that equals 1 if $\Delta q_i^t \times \Delta q_j^t < 0$, and zero otherwise.

<u>Empirical Results</u>:

The data are summarized in Table 1 (correlations) and Table 2 (compensating changes). The lower block in each table records the behavior of the non-OPEC producers; i.e. the control group whose behavior is presumed to establish the competitive norm for parallel action. For comparison, the upper block records the behavior of OPEC members. Even on the basis of very cursory examination, it is possible to say that the two blocks hardly resemble each other.

The average correlation among output changes for OPEC members is 22.9%, whereas for non-OPEC producers the correlation is only 2.4%. The perfectly competitive benchmark implies a 0% correlation among changes induced by idiosyncratic cost shocks. The additional effect of exposure to common demand shocks would tend to increase the observed correlation, and the difference between 0% and 2.4% would incorporate that effect, which seems quite small in our sample.

If we take the competitive norm to be a correlation of 2.4%, hypothesis H_1 can be rejected at the 5% significance level for ten of the eleven OPEC members, and the remaining member (Qatar) is borderline.[7] Thus, the OPEC members quite uniformly display a degree of parallel action that significantly exceeds the competitive benchmark. Of the eight non-OPEC producers, two (Norway and the UK) exhibit a distinctively strong positive correlation with the output of other non-OPEC producers, while the other six remain essentially at or below the competitive norm.

It might be noted that what the UK and Norway have in common is a record of strong and sustained output growth, triggered in the late 1960s by the discovery and development of the first North Sea oil fields. That expansion happens to have paralleled the general growth in non-OPEC output over the past thirty years, and creates in turn the observed positive correlation seen in Table 1. It would not be misleading to interpret this pattern as a geologically induced correlation, rather than the type of behaviorally induced correlation we have attempted to model. In any event, the comparatively high correlations found among OPEC members cannot be attributed to the same cause. Indeed, the correlation between the changes in the output of OPEC members and non-OPEC producers averages only 6.7% during our period. OPEC members tend to adopt parallel output adjustments only versus other OPEC members, not versus outsiders.

Regarding the second hypothesis, H_2, the average frequency of compensating monthly changes observed within OPEC is 33.0%, but outside OPEC it grows to 41.5%

(see Table 2). Based on the impact of idiosyncratic cost shocks alone, the perfectly competitive norm would be 50%, but that benchmark must be reduced somewhat by the impact of common demand shocks. The difference between 41.5% and 50% would incorporate that difference.[8] If we take 41.5% to be the competitive norm, it can be seen from Table 2 that no OPEC member exhibited compensating changes so frequently.

To assess the statistical significance of the observed difference between groups, we estimate and test the coefficients of a logistic regression model of the form:

$$\ln\left[\frac{f_{ij}}{1-f_{ij}}\right] = \alpha + X_{ij}\beta + \varepsilon_{ij},$$

where the X_{ij} is a variable that takes the value "1" for pairings of OPEC producers and "0" for non-OPEC. An estimate of β that is significantly below zero would reflect a reduced frequency of compensating changes among OPEC members and constitute a rejection of hypothesis H_2. The results are shown in Table 3.[9]

The estimated value of β is –0.36, with an associated t-value of -2.45. Thus, hypothesis H_2 is easily rejected at the 5% significance level, and this result constitutes rejection of the perfectly competitive, frictionless cartel, Cournot, Stackelberg, and Bertrand models. Indeed, it appears that members of OPEC have behaved collusively, albeit subject to a level of transaction costs that severely restrict their ability to pursue

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[7] Since $\rho \neq 0$ under H_1, the sample correlation coefficient, r, is biased and its distribution has a complicated form. We therefore apply Fisher's transformation, $z = \tanh^{-1}(r)$, where z is an asymptotically normal variate with mean = $\tanh^{-1}(\rho)$ and variance $\approx 1/(N-3)$. See Morrison (1976, pp. 104-105).

[8] The figure for non-OPEC producers should probably be higher than 41.5%, due to the fact that monthly data on Chinese oil production were sparse during the early part of our sample, resulting in many months of no reported change in output. Each such instance of non-reporting biases the observed frequency of compensating changes toward zero. During the 1970s and early 1980s, for example, the frequency of recorded compensating output changes between China and other non-OPEC producers was only 10.9%. Our results and conclusions would only be stronger if this portion of the Chinese sample were ignored.

joint profit maximization. The conduct of OPEC members can not reasonably be construed as competitive or “merely interdependent.” The degree of parallel action observed among OPEC members over the past thirty years is not consistent with that.

V. Summary and Conclusions

Although *parallel pricing* behavior serves, at best, as an ambiguous indicator of market structure, *parallel production* behavior may provide a clearer signal. Whether measured in terms of the correlation among output changes, or the frequency of compensating output adjustments, the degree of parallel action among producers varies predictably with the degree of interdependence among firms and provides an additional means for distinguishing among alternative behavioral hypotheses.

As for the standard market models, our measures of parallel action are expected to vary inversely with the degree of interdependence: more parallelism among perfectly competitive firms, less among interdependent oligopolists, and even less among collusive members of a frictionless cartel. The exception to this pattern is the case of a bureaucratic cartel or production syndicate that is saddled by transactions costs—costs that tend to increase whenever non-parallel actions are undertaken. If such transactions costs are sufficiently high, the degree of parallelism among members of a bureaucratic cartel might even exceed the perfectly competitive benchmark.

In certain circumstances, these relations may facilitate tests that distinguish empirically between alternative behavioral hypotheses—notwithstanding the inherent uncertainty that usually surrounds values of underlying structural parameters like the slopes of the demand curve and marginal cost curves. Our analysis of OPEC production

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[9] Estimates were obtained using the method of Weighted Least Squares, which under standard assumptions

histories provides one such example where the results are quite clear. In contrast to the generally inconclusive results of previous analyses, our tests demonstrate that OPEC is much more than a non-cooperative oligopoly, but much less than a frictionless cartel. All traditional explanations of OPEC behavior (i.e., competitive, Cournot, dominant-firm, etc.) are strongly rejected, except the hypothesis that OPEC acts as a bureaucratic cartel; i.e., a collusive enterprise weighed down by the cost of forging consensus among its members.

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regarding the ε_{ij} provides unbiased and efficient coefficient estimates.

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Table 1:
Correlations Between Monthly Production Changes

... vs. Rest of OPEC	correlation	H1: $\rho > 2.4\%$ test statistic
Algeria	12.3%	1.85 *
Indonesia	20.4%	3.40 **
Iran	18.3%	2.99 **
Iraq	11.4%	1.68 *
Kuwait	44.4%	8.41 **
Libya	27.5%	4.79 **
Nigeria	21.8%	3.67 **
Qatar	10.9%	1.59
UAE	38.4%	7.07 **
Venezuela	18.5%	3.03 **
Saudi Arabia	27.7%	4.83 **
OPEC average	22.9%	
… vs. Non-OPEC	correlation	
Canada	-5.3%	-1.42
China	1.8%	-0.11
Egypt	-1.0%	-0.63
Mexico	-8.8%	-2.08
Norway	17.3%	2.80 **
Russia	-3.6%	-1.11
UK	13.0%	1.98 *
US	5.6%	0.60
Non-OPEC avg.	2.4%	

*** significant at 1% level.*
** significant at 5% level.*

Note: "Rest of OPEC" consists of all OPEC production, less the production of any OPEC country to which it is compared. "Non-OPEC" consists of worldwide production net of OPEC and the production of any Non-OPEC country to which it is compared.

Table 2:
Frequency of Compensating Monthly Production Changes

… vs. Rest of OPEC	f_{ij} frequency
Algeria	**16.7%**
Indonesia	**31.3%**
Iran	**35.4%**
Iraq	**33.6%**
Kuwait	**34.9%**
Libya	**28.7%**
Nigeria	**38.9%**
Qatar	**34.7%**
UAE	**36.2%**
Venezuela	**37.6%**
Saudi Arabia	**35.4%**
OPEC average	**33.0%**
… vs. Non-OPEC	
Canada	**51.4%**
China	**27.1%**
Egypt	**30.0%**
Mexico	**43.4%**
Norway	**45.3%**
Russia	**45.6%**
UK	**38.7%**
US	**50.4%**
Non-OPEC avg.	**41.5%**

Note: "Rest of OPEC" consists of all OPEC production, less the production of any OPEC country to which it is compared. "Non-OPEC" consists of worldwide production net of OPEC and the production of any Non-OPEC country to which it is compared.

Table 3: Estimated Logistic Equation

(asymptotic t-statistics in parens)

Monthly Observations				
Model/Sample	constant	OPEC	R^2	N
1. Pooled OPEC & Non-OPEC:	-0.329 ** (-3.00)	-0.359 ** (-2.45)	0.12	19
2. Same, but less China:	-0.252 * (-2.44)	-0.436 ** (-3.24)	0.29	18

Note: Left-hand variable equals logit of frequency of compensating changes.

** Significantly different than zero, 1% level.

* Significantly different than zero, 5% level.

Figure 1: Impact of Idiosyncratic Cost Shocks (λ_1 and λ_2 reflect the degree of interdependence)