Massachusetts Institute of Technology
Center For Energy and Environmental Policy Research

Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis*

James L. Smith

Reprint Series Number 177

**Reprinted from The Energy Journal, Vol. 26, No. 1. (2005), with kind permission from International Association for Energy Economics.*

Inscrutable OPEC?
Behavioral Tests of the Cartel Hypothesis*

*James L. Smith***

Although OPEC is commonly viewed as a syndicate of producers engaged in cooperative efforts to restrict production and raise price, to date there is a surprising dearth of supporting statistical evidence to that effect. I show that standard statistical tests of OPEC behavior have very low power across a wide range of alternative hypotheses regarding market structure. Consequently, it is difficult, given the current availability and precision of data on demand and costs, to distinguish collusive from competitive behavior in the world oil market. I apply a new, production-based approach for examining alternative hypotheses and find strong evidence of cooperative behavior among OPEC members. My results also suggest that OPEC's formal quota mechanism, introduced in 1982 to replace a system based on posted prices, increased transactions costs within the organization. Statistical evidence is mixed on the question of whether Saudi Arabia and other core producers have played a special role within the cartel. (JEL: D43, L11, L13, Q41)

The Energy Journal, Vol. 26, No. 1.

* A preliminary version of this paper, entitled "OPEC and the Loch Ness Monster," was presented during June 2002 at the Institut Français du Pétrole in Paris, and at the 25th Annual International Conference of the International Association for Energy Economics in Aberdeen, Scotland. Many people have provided helpful comments on an earlier draft. I am particularly indebted to M. A. Adelman, A. F. Alhajji, Denis Babusiaux, Robert Bever, Michael Christiansen, Jean-Phillipe Cuielle, Carol Dahl, Peter Davies, John Gault, James Griffin, William Hogan, Clifton Jones, Dan Levin, Gary Libecap, Stephen McDonald, John Mitchell, Axel Pierru, Paul Tempest, Rex Thompson, Campbell Watkins, and Paul Weston, along with two anonymous referees. None of those individuals is responsible for any errors that might remain. The author gratefully acknowledges research support from Southern Methodist University, the University of Houston, and the MIT Center for Energy and Environmental Policy Research.

** Department of Finance, Southern Methodist University.

INTRODUCTION

Since OPEC first achieved notoriety in the early 1970s, substantial public interest and numerous scholarly investigations have focused on the collective decisions and economic impact of this association of sovereign oil producers. Conflicting interpretations of OPEC and its influence have been advanced, each built from a different blend of the principles of competitive, collusive, and monopolistic behavior. Whether one views OPEC as a benign, potent, or simply highly erratic influence on the market depends largely on one's choice among these different perspectives and the assumptions that frame them.

The competing OPEC stories find support in different quarters. One can cite bits and pieces of evidence that are consistent with each of the various hypotheses, and these have been used to rationalize the conflicting points of view and sustain debate. Having surveyed the first decade of OPEC research, Gately (1984) concluded that it remained "an open question how best to design a model of the behavior of OPEC." Hoping to steer subsequent research efforts in a direction that might help to narrow the field, Griffin (1985, p. 954) pointed to one fundamental problem:

> The standard practice to date has been to reach onto the shelf of economic models, to select one, to validate its choice by pointing to selected events *not inconsistent* with the model's predictions, and then to proceed with some normative exercise. (emphasis added)

As Griffin realized, evidence that is "not inconsistent" with a particular point of view is hardly conclusive, and certainly not a proper basis for choosing among the alternatives.[1] This weighs heavily in the current context because, as shown below, behavioral models of OPEC from the entire spectrum of market structures give many predictions that are indistinguishable from one another, at least at the level of empirical certitude that characterizes the world oil market. The consequence, as I argue in the preliminary sections of this paper, is that much of the evidence that has been cited regarding OPEC's behavior is mutually consistent with a wide range of apparently conflicting models. This lack of conclusive and systematic evidence is especially remarkable in light of the pervasive view (held by laymen and experts alike) that OPEC does indeed engage in collusive

1. This criticism is not new in the industrial organization literature, having played a central role in Stigler's (1964) attack upon those "immortal theories" that defied falsification for lack of testable hypotheses.

behavior.[2] In the latter sections, I outline and test some new behavioral predictions that may help us to distinguish among the competing hypotheses.

II. NOTES ON THE LITERATURE

The previous empirical literature, which includes Griffin's (1985) path-breaking inquiry plus a series of contributions by Loderer (1985), Geroski, Ulph, and Ulph (1987), Green (1988), Jones (1990), Dahl and Yücel (1991), Griffin and Nielson (1994), Gülen (1996), Gault, et. al. (1999), Alhajji and Huettner (2000a & 2000b), Spilimbergo (2001), and Ramcharran (2002), remains largely inconclusive regarding the behavior and impact of OPEC, despite the best efforts of those authors. Few interesting hypotheses have been rejected and therefore little has been clarified regarding OPEC's actual or intended influence on the market. Behavioral patterns are sometimes discernable, but those that have been found tend to be consistent with multiple hypotheses.

For example, Gülen (1996, p. 43) looks for indications that the output levels of individual OPEC members tend to move in parallel because, as he notes: "If OPEC was an effective cartel sharing the market among its members, there would be a long-run relationship between each member's production and total OPEC output." But, although parallel movement is not inconsistent with the cartel hypothesis, neither is it inconsistent with the competitive hypothesis since the output levels of perfectly competitive firms would likewise be expected to move together in response to demand shocks and systematic cost fluctuations that impact the entire industry. Gülen's search, therefore, is for evidence that would at best be inconclusive. Griffin (1985, p. 957) also noted the empirical tendency for parallel movement among OPEC members' production levels and interpreted parallelism as evidence that OPEC is a "real cartel with at least partially effective output coordination." The same critique applies: circumstances that would induce cartel members to increase or decrease their outputs in concert would also induce perfectly competitive firms to "coordinate" their output levels.[3] How to distinguish the two empirically?

Alhajji and Huettner (2000b) focus on the estimated price elasticity of demand for OPEC (or alternatively, Saudi) oil, noting in particular that a monopolist would not choose to operate on the inelastic portion of its demand curve. Thus, estimated demand elasticities numerically below –1 would constitute evidence not inconsistent with the cartel hypothesis. Neither would such results

2. The most recent expression of this view came from Claude Mandil, Executive Director of the International Energy Agency, who said in open session at the July 2004 conference of the IAEE in Washington DC: "For over three decades, OPEC members have colluded to manage the price of oil." In this same spirit, the reader can find numerous references carefully distilled from close observation and richly detailed assessments of the diverse aspects that characterize OPEC and its membership. Notable examples include the works by Adelman (1995 and 2002), Mabro (1998), Amuzegar (1999), Claes (2001), Mitchell et. al. (2001), Kohl (2002), and Parra (2004).

3. Alhajji and Huettner (2000a, page 126) have previously noted this ambiguity.

be inconsistent with the perfectly competitive hypothesis, however, since it is quite easy to envision market conditions under which a perfectly competitive industry comes to equilibrium at a point on the upper half of the demand curve (i.e., where market demand is elastic).[4]

As further example of the ambiguity of market predictions, consider Libecap's (1989) hypothesis, also later employed by Dahl and Yücel (1991), that so-called "swing" producers (such as the Texas Railroad Commission in Libecap's context or Saudi Arabia and/or the cartel "core" for Dahl and Yücel) should be expected to exhibit larger proportionate changes in production than the rest of the market. The whole production of an individual swing producer is vulnerable, after all, to relatively small percentage fluctuations in aggregate output from the rest of the group. On this basis, a high coefficient of variation in individual output, compared to the market as a whole, would constitute evidence not inconsistent with the status of a swing producer. On the other hand, neither is a high coefficient of variation inconsistent with the status of a perfectly competitive producer. For example, if output variations of all producers are essentially random (e.g., governed by weather, unpredictable drilling results, unscheduled maintenance, etc.), then the coefficient of variation for individual producers will necessarily exceed that of the group as a whole (because relative to the random fluctuations in output, the group enjoys greater benefits of diversification than the individual producer).[5] The same would be true in any competitive industry to the extent that random output fluctuations at the level of the individual producer are significant. How then to distinguish the swing producer from the competitive producer?

Separately, Dahl and Yücel (1991, p. 126) observe that low-cost producers in a profit-maximizing cartel would be expected to produce more than high-cost producers, and that an indicator of marginal cost should therefore enter significantly (and negatively) into the production equation for cartel members, a

4. Alhajji and Huettner (2000b, p. 45) actually claim to have *rejected* the hypothesis that OPEC's demand is elastic, which as they indicate would constitute evidence that "OPEC is not a *profit-maximizing* cartel." (emphasis added) That result would not, however, rule out the possibility that OPEC might be acting as a *cautious or restrained* cartel; i.e., raising the market price somewhat, but not to the full degree of a profit-maximizing monopolist. In other words, the elasticity-based test must in principle be inconclusive on the question of whether OPEC has affected the market price. As it happens, Alhajji and Huettner's statistical rejection of the elasticity hypothesis appears to have been in error (see note 11), so the question is moot.

5. Let there be N producers in the industry. Denote the i^{th} producer's output level q_i, with mean μ and variance σ^2. If output fluctuations are assumed to be independent, aggregate output is then given by $Q = \Sigma q_i$, with mean $N\mu$ and variance $N\sigma^2$. By definition, the coefficient of variation of an individual firm's output level is $c = \sigma/\mu$, and for the industry it must be $C = \sqrt{N}\sigma/N\mu = c/\sqrt{N} < c$.

result which they find in the data.[6] However, the same volumetric relationships—low-cost producers dominating high-cost producers—would be expected to hold among perfectly competitive producers, and therefore the pattern of evidence is again consistent with models located at opposite ends of the economic spectrum and the results are inconclusive.

Further ambiguity comes from the study by Gault, et. al. (1999) of OPEC's apportionment of total output target among individual members; i.e., the determination of individual quotas. Although the authors were able to form a preference for certain models over others on the basis of parsimony, they found that none of the four tested models of quota assignments was statistically inconsistent with the data.

Thus, despite a continuing series of statistical investigations that carefully scrutinize pricing impacts as well as production decisions, the empirical literature has failed to produce clear evidence regarding the nature of OPEC behavior, whether competitive or otherwise. There are some notable individual exceptions, of course—instances where particular researchers have been able to reject one model or hypothesis in favor of another. However, the pattern of such rejections is sparse and confined for the most part to the domain of highly specialized and therefore relatively uninteresting hypotheses.

Griffin (1985), for example, is able to reject the "constant market sharing" variant of the cartel hypothesis in ten of eleven instances, but this is an extreme proposition (i.e., members' take fixed shares in total output independently of the price level) that would characterize the production shares of a profit-maximizing cartel only by coincidence. In general, shares of cartel members should be expected to fluctuate with the price level in accordance with the differential elasticities of members' individual marginal cost schedules.[7] Griffin is not able to reject this more general variant of the cartel hypothesis in any of the eleven instances investigated. Jones (1990), who extended Griffin's estimates to a later time period, finds essentially the same result.

Griffin (1985) is also able to reject in all ten instances the "strict" version of the target revenue hypothesis (which maintains that producers vary production inversely with price to maintain a constant level of revenue commensurate with exogenous investment needs). However, the "partial" variant of this hypothesis, in which exogenous investment requirements are assumed to drive production, but to a lesser degree, can be rejected in only one of the ten instances.[8] The results of Dahl and Yücel (1991), based on a larger sample of data, are consistent with Griffin: the strict version of the target revenue model can be rejected in every instance, but the

6. On purely theoretical grounds, output allocations to individual members should vary inversely with the average cost of production, whereas marginal costs should be equalized in order to minimize the total cost of the cartel's output. In practical terms, however, there is enough ambiguity between empirical measures of average and marginal cost to perhaps overlook this distinction.

7. Of course, the shares of competitive producers would be expected to fluctuate similarly.

8. Recall that false rejections (type I errors) are expected to occur with certain limited frequency in accordance with the level of significance of the test employed.

partial variant can never be. Alhajji and Huettner's (2000a) detailed examination of the target revenue hypothesis also finds it relatively easy to reject the extreme form, but much more difficult to reject the more plausible, "weak" forms of this model.

Loderer's (1985) approach is somewhat different, eschewing any behavioral model by which to describe or predict OPEC's specific actions in lieu of a simple empirical test of market impact. Specifically, Loderer takes as null hypothesis the proposition that OPEC policies (as agreed upon and announced at the series of 34 regular OPEC meetings that were held during the interval 1974-1983) had no impact on market prices. A rejection of the null would establish market impact and therefore open the door to a line of more specific questions regarding the nature of OPEC policies and actions that created the impact, and the identity of OPEC members that were instrumental in achieving this result. As Loderer acknowledges, however, rejection of the null would be "consistent with several explanations of the nature of OPEC. It could, for instance, be an effective cartel, or it could be an organization of noncooperative oligopolists." Price impact, in other words, is a necessary but not sufficient condition for the existence of an effective cartel. One is left again with inconclusive results even in the event that the null hypothesis is rejected. In fact, Loderer is unable to reject the null hypothesis of no impact for the years, 1974-80, when the most pronounced price increases occurred. Only during the last three years of his sample, 1981-83, (during which prices were generally in decline) is the evidence strong enough to reject the null; but even for that short subinterval one is then left to sort through unspecified alternatives: collusion, non-cooperative oligopoly, mere interdependence, etc.

Two particularly enlightening empirical studies argue that OPEC's behavior varies over time—vacillating between cooperative and competitive modes, depending on circumstances—and therefore cannot be adequately described by any simple hypothesis. Geroski, Ulph, and Ulph (1987) specify a partially altruistic objective function for each OPEC member that incorporates variable weights on its own profits and the profits of other members. Within this framework, the authors are able to reject the "constant-behavior" hypothesis, and moreover to demonstrate that observed actions conform roughly to the "tit-for-tat" game strategy (at least during their sample period of 1966-1981), which is a time-varying combination of cooperative and competitive modes of behavior. Similarly, Griffin and Neilson (1994) find evidence that, subsequent to the oil price crash of 1985-1986, Saudi Arabia adopted a tit-for-tat production strategy that alternately disciplines and rewards other cartel members. While both of these studies advance considerably our comprehension of the richness and complexity of OPEC behavior, they also reinforce the notion that it is possible to find bits of behavioral evidence in the historical record that are consistent with a wide range of alternative hypotheses—therefore making it difficult to reject any.[9]

9. These findings bolster Adelman's long-held position that OPEC is an inconsistent, sometimes bumbling, sometimes cohesive, but always vacillating federation of producers. See, for example, Adelman (1980, 1982, 1995, and 2002).

Some Misreported Results

Apart from the results described above, a number of other inferences presented in previous studies are simply incorrect and must be discounted. Spilimbergo (2001, page 349 and Table 3), for example, makes the elementary logical mistake of concluding that failure to reject his null hypothesis (i.e., that OPEC acts competitively) constitutes a rejection of the alternative. The proper interpretation is that his results are not strong enough to distinguish between the null hypothesis and its alternative, and therefore simply inconclusive. Dahl and Yücel (1991, page 121 and Table 1) commit the same error in reporting that the hypothesis of dynamic behavior (long-term planning horizon) among OPEC producers is "strongly rejected," when in fact their statistical result establishes only that the null hypothesis of non-dynamic behavior (short-term planning horizon) can not be rejected.

Alhajji and Huettner's (2000b) test of whether OPEC producers have exploited their market power by limiting output to the point where marginal cost equals marginal revenue is hampered at the outset by the authors' reliance on flawed cost estimates that would seem to misrepresent the level of marginal cost in each producing country, and their failure to account for the uncertainty that surrounds these estimates (cf. section III of this paper).[10] More troubling is the fact that the demand elasticities they report, and upon which their tests are

10. Their marginal cost estimate for each OPEC country consists of three components: (a) extraction cost, (b) royalties, and (c) per barrel military expenditures (which proxy for "security costs" of production). Each component seems badly flawed: (a) the extraction cost estimate makes no provision for geological and operating differences between countries or for economic changes over the boom-bust cycle of extraction—it is simply assumed to be 50 cents per barrel in 1970 and increasing thereafter at the rate of 3 percent per annum; (b) royalties are assumed to be a uniform 17 percent of revenues for all OPEC countries, but since the respective governments are the owners of the resource, they are paying this component of "cost" to themselves and it is only an illusion; and (c) the military expenditures of each country can be rationalized in part as protection to ensure the security of that nation's oil reserves and production facilities, but those expenditures remain the same whether output rises or falls by 10 percent; i.e., they are fixed rather than variable.

built, are inconsistent with their estimated demand equations; and the corrected elasticity estimates would in most cases reverse their reported rejections of the null hypothesis.[11]

Dahl and Yücel (1991) and Gülen (1996) test the null hypothesis that production levels of OPEC members are not cointegrated, where rejection would imply that production levels tend to move together. It has already been noted, of course, that outputs might be expected to move together whether producers are competitive rivals or cartel collaborators, so rejection of the null hypothesis would leave matters quite unclear. In any event, Dahl and Yücel are almost never able to reject the null hypothesis, which leaves matters equally unclear. Gülen is able to reject the null hypothesis more often, but the pattern of rejections (across time and countries) is still infrequent and erratic.[12] Moreover, cointegration tests presume that production series from the respective regions are nonstationary—which is to say unbounded. The very foundation of this approach, therefore, hardly seems consistent with the physical manner in which oil resources are known to be found and produced. The statistical power of cointegration tests is also known to be low. Consider, for example, two producers: one whose production varies randomly over time within some fixed band, and another who makes periodic production adjustments that exactly offset the variations of the first. Although the second producer performs the role of swing producer perfectly, the cointegration approach would not detect it since neither production series is nonstationary, which precludes the cointegration test in the first place.[13]

11. Alhajji and Huettner (2000b) estimate the elasticity of world oil demand (E_w) to be -0.251 and the elasticity of non-OPEC supply (E_{no}) to be 0.290 (see their Table 2). The elasticity of residual demand for OPEC oil (E_o) can be inferred from the identity: $E_o = E_w/s - E_{no}(1\text{-}s)/s$, where s = OPEC's share of world output. The authors report only a few of the computed values of E_o, on which their tests are based. For example, they give the figure $E_o = -0.1644$ for the first quarter of 1983 and claim that in no quarter was E_o algebraically below –0.2209. By the preceding formula, their 1983 figure would imply that OPEC produced 119% of worldwide output (s = 1.19) during that quarter. Based on the values of E_w and E_{no} in their Table 2 and OPEC's *actual* market share for first quarter of 1983 (30.1% according to monthly production statistics of the U.S. Energy Information Administration), the correct value for the elasticity of residual demand for OPEC oil that quarter would be $E_o = -1.507$ (not –0.1644 as reported). Small discrepancies in the reported elasticity might result from differences in quarterly market shares computed from consumption versus production data (the difference representing changes in inventories), but the apparent discrepancy here is too large to be accounted for in that manner. Corrected values for the elasticity of residual demand for OPEC oil during the authors' entire estimation period range from –1.66 to –0.67, and fall into the elastic range 58 percent of the time, including the entire subinterval from April 1981 to November 1992. These corrected values are more consistent with the results of Geroski, Ulph, and Ulph (1987, page 81) who in their earlier study found the elasticity of demand for OPEC oil to be close to or less than –1.00 after 1973.

12. The scope of statistical transformations that Gülen must apply to the production series to facilitate the cointegration tests is also surprisingly inconsistent, varying in the case of Nigeria from zero monthly lags (for the 1965-1993 interval) to eleven monthly lags (for the 1974-1993 subinterval).

13. Based on cointegration tests, Libecap (1989, page 846) was unable to find any evidence that Texas played the role of swing producer under the guise of the Interstate Oil Compact Commission, although the IOCC clearly acted as a well-documented and highly successful production cartel in the U.S. oil market throughout the middle third of the twentieth century.

Green (1988) argues, but without providing any measure of statistical significance, that OPEC appears to act as a swing producer over the seasonal cycle—raising production during the colder winter months when demand is peaking and reducing production during the remainder of the year. It is not clear why competitive producers would not be expected to respond similarly to these seasonal demand cycles, either through direct production increases or inventory liquidation. Moreover, the underlying data seem not to support Green's thesis: Holding other things constant, OPEC's average production is lowest during the first two months of the year (see Green's Figure 1), those being the months that are typically the coldest and which would (by Green's argument) provide the greatest scope for OPEC to increase its own output without upsetting the market price. Estimates of residual demand for OPEC oil by Geroski, Ulph, and Ulph (1987, p. 81) show the seasonal and temperature variables to be statistically insignificant in any event.

Finally, consider Griffin's (1985) reported rejection of the "competitive" hypothesis in five of the eleven OPEC countries examined. This result certainly constitutes a substantial piece of evidence regarding one of the most central issues in the OPEC debate. For that reason alone, it bears scrutiny. Due to data limitations that Griffin readily acknowledged, his "competitive" model is limited to a simple bivariate linear equation that relates a country's output to the prevailing price level. Griffin's "rejection" of the competitive hypothesis is caused in each instance by the finding of a significant *negative* relationship between a given country's output and the market price. What is potentially misleading is the exclusion of costs from the estimated relationship. Competitive behavior implies that, *if a producer's costs are held constant,* then price and output should move in concert. Experience within the petroleum industry, particularly during Griffin's sample period (1971-1983), has been that each instance of significant price escalation has seen significant cost escalation too, as the rush of drilling activity drove factor prices upwards. The cost data that would control for this confounding effect were not available to Griffin, and therefore excluded from the estimated equation. Thus, it is not clear whether the reported rejections signify genuine deviations from competitive behavior or the impact of omitted variables.[14] Jones (1990) was able to reject the competitive hypothesis for only two of eleven OPEC members in his extension of Griffin's analysis to the 1983-1988 interval. Ramcharran (2002) was likewise able to reject the competitive hypothesis for only two OPEC members in his more recent extension.[15] Watkins and Streifel (1998) obtained similar, but equally ambiguous results for the OPEC segment of their much broader study of oil supply functions: among the

14. This effect may be more pronounced in the U.S. than in the OPEC countries, and Adelman's (1992) results suggest that even in the U.S. its importance is moderated by other factors. In fairness, my results (reported later) tend to corroborate and strengthen Griffin's conclusions.

15. Ramcharran is able to reject only twice at the conventional 5% significance level. He reports a greater number of rejections, but upon inspection, those are based on a looser standard.

eleven OPEC members, five showed a positive relationship between the price of reserves and the rate of reserve additions (of which two were significant), and six showed a negative relationship (again two were significant).

III. THE POWER TO DISTINGUISH MONOPOLY FROM COMPETITION

Can the behavior of a monopolist (or cartel) be distinguished empirically from that of perfectly competitive firms? Since market power is ultimately used to raise prices, it seems natural to approach this problem from the perspective of pricing behavior, where a significant deviation of price from marginal cost may be taken as evidence of market power and monopoly rents. On the other hand, Phlips (1996), in his presidential address to the European Economic Association, challenges this approach based on what he terms the principle of "indistinguishability."[16] He would argue, in brief, that our empirical knowledge of cost functions and demand curves is generally too vague and imprecise to support statistically significant conclusions regarding the correspondence of price and marginal cost.

An alternative approach is to ignore price-cost margins and focus directly on production decisions; i.e., to test comparative static production responses to exogenous shocks for evidence of interdependence among firms. If structured properly, production-based tests may succeed in some cases where pricing tests fail. In the remaining sections of this paper, I describe such production tests and apply them to OPEC. The results lead to reasonably strong inferences regarding the degree of interdependence and collusion among that group of oil producers. Before presenting those results, however, it is instructive to examine Phlips' critique of pricing analysis in the context of the world oil market.

Price Analysis

Consider a group of producers, ***G***, who are suspected of colluding. In addition, let there be a "competitive fringe" of price-taking producers whose output supplements that of the suspected cartel. The question is whether it is possible to properly diagnose the actions of the cartel. I set forth the two possible extremes regarding their behavior:

H_o: *(perfect competition)* $MC_i = P, \quad \text{all } i \in \boldsymbol{G}.$

H_a: *(perfect cartel–multi-plant monopoly);* $MC_i = P(1+1/\varepsilon_G), \quad \text{all } i \in \boldsymbol{G}.$

16. See also Harstad and Phlips (1994).

where:

$Q_G(P) = Q_d(P) - Q_f(P)$ (total demand less fringe supply)

$\varepsilon_G = \varepsilon_d/s - \varepsilon_f(1\text{-}s)/s$ (elasticity of residual demand)

$1\text{-}s = Q_f/Q_d$ (fringe market share)

Even if the alternative hypothesis is true, the ability to reject the null depends on our having good estimates of marginal cost and the elasticity of residual demand. The conventional one-sided test (with significance level = α) stipulates:

$$\text{Reject } H_o \text{ if: } \quad \frac{P - \overline{MC}}{\sigma_{\overline{MC}}} > z_\alpha \tag{1}$$

Otherwise: Do not reject H_o;

where:

$\overline{MC}$ = unbiased estimate of marginal cost,

$\sigma_{\overline{MC}}$ = standard deviation of $\overline{MC}$

The power of this test is by definition the probability of rejecting the null hypothesis given that the alternative is true. Using *mc* to represent the expected value of $\overline{MC}$, one may write:

$$\begin{aligned}
\text{Power} &= \Pr\left[\frac{P - \overline{MC}}{\sigma_{\overline{MC}}} > z_\alpha \;\middle|\; mc = P\left(1 + \frac{1}{\varepsilon_G}\right)\right] \\
&= \Pr\left[\overline{MC} < P - z_\alpha \sigma_{\overline{MC}} \;\middle|\; mc = P\left(1 + \frac{1}{\varepsilon_G}\right)\right] \\
&= \Pr\left[\frac{\overline{MC} - P(1 + 1/\varepsilon_G)}{\sigma_{\overline{MC}}} < \frac{P - z_\alpha\sigma_{\overline{MC}} - P(1 + 1/\varepsilon_G)}{\sigma_{\overline{MC}}}\right] \\
&= \Pr\left[z < -z_\alpha - \frac{P}{\varepsilon_G \sigma_{\overline{MC}}}\right]
\end{aligned} \tag{2}$$

where the last step depends on the assumption that the cost estimate is normally distributed around its mean, and z represents a standard normal variate.

Phlips' point is that the power of this test will depend on the precision of our marginal cost estimate, which I express in terms of the coefficient of variation (λ):

$$\lambda = \sigma_{\overline{MC}}/mc.$$

After substituting this in Equation 2, the power can be written as:

$$\text{Power} = \Pr\left[z < -z_{\alpha} - \frac{P}{\varepsilon_G \lambda P(1 + 1/\varepsilon_G)} \right]$$

$$= \Pr\left[z < -z_{\alpha} - \frac{1}{\lambda(1 + \varepsilon_G)} \right]. \qquad (3)$$

Note that $(1+\varepsilon_G) < 0$ under the alternative hypothesis, and that $\Pr[z < -z_a] = \alpha$ by definition, thus the power of the test can not drop below α. But, for the power to substantially exceed α (which gives merely the probability of rejection due to mistaken judgment), the denominator of the right-hand term must be small. There are three conclusions, none surprising:

a. The power to distinguish competition from collusion increases as precision of the marginal cost estimate improves ($\lambda \rightarrow 0$);
b. The power to distinguish competition from collusion also increases as the elasticity of residual demand decreases in absolute value ($\varepsilon_G \rightarrow -1$ from below);
c. The power of the test is even lower than reported above if collusive producers occasionally commit random pricing errors; in which case the alternative hypothesis must be restated as $MC_i = P(1+1/\varepsilon_G) + e_i$, where e_i represents random error in attaining the first-order conditions of profit maximization. The true power would be obtained by adding the optimization standard error to the cost estimation standard error in the foregoing expressions.[17]

Even under the favorable but unlikely assumption that members of the cartel never make pricing errors, the power to reject the competitive hypothesis is extremely low, at least under realistic assumptions regarding the structure of

17. On the other hand, if the cartel or monopolist misestimates the relevant demand elasticity, and systematically overshoots the optimal price, then the power to reject the competitive hypothesis would be enhanced. Adelman (1985, pp. 146-150) argues persuasively that this was true of OPEC during the 1970s

the world oil market and the precision of our cost estimates. This is evident from the portions of the power function I have calculated from Equation 3 and graphed in Figure 1. For purposes of this illustration, Saudi Arabia alone is assumed to constitute the "cartel core," with other OPEC members and all non-OPEC producers included in the competitive fringe.

In Figure 1, the elasticity of world demand is assumed to be –0.5.[18] The elasticity of supply from the rest of the world (the aggregate of all non-Saudi production) is assumed to be +0.3, and the Saudi market share of total output is assumed to vary between 3% and 18% (roughly equivalent to the historical low and high). Finally, the precision (λ) of the estimate of Saudi marginal cost is permitted to vary between 0.l0 and 0.70. Panel A of the figure shows the power of a 5% significance level test, and reveals that a random sample is very unlikely to reject the null hypothesis of competitive pricing unless marginal cost is estimated with high precision ($\lambda \leq 0.3$). The possibility of rejecting at the 1% significance level is really quite remote, as shown in Panel B.

One could hope, if the Saudi market share were at the very high end of the historical range, and if very exact estimates of marginal cost could be produced, that the 5% significance test could be counted on to reject the competitive hypothesis—if it is indeed false. The Saudi's average share, however, is roughly 12%. And the precision of marginal cost estimates seems best approximated by a coefficient of variation near 0.50.[19] Subject to these conditions, the ability based on pricing behavior to reject the competitive hypothesis, even if it were false, is extremely low—hardly greater than the probability of committing a Type-I error.

Output Analysis

Here I describe an alternative approach that attempts to distinguish market structures based on output behavior. This approach focuses on the prevalence of offsetting or "compensating" production changes among potential rivals. Compensating production behavior is the opposite of parallel action. One producer increasing output to offset the decline of another is an example of compensating behavior. Such behavior arises for different reasons, and with varied frequency, under alternative forms of market organization.

In Cournot oligopoly, for example, rivals' reaction functions ensure that whenever an idiosyncratic cost shock would cause one producer's output to fall, other producers would partially accommodate by increasing their own levels of output. Within a perfectly managed cartel (i.e., frictionless multi-plant monopoly), the cartel manager pushes such accommodation to the extreme,

18. A greater demand elasticity would only make matters worse for the power of the test since the effect of greater elasticity is to push the optimal monopoly price closer to the competitive level.

19. Analysis of the estimates of marginal costs for OPEC members produced by Adelman and Shahi (1989) suggest that the coefficient of variation is roughly 0.50 (see appendix for explanation and derivation of this result).

constantly shifting output among producers to ensure that least-cost operation is maintained—something a Cournot oligopoly is not able to achieve. Cost shocks experienced by members of the cartel would therefore generate offsetting changes in outputs to an even greater extent than in the Cournot equilibrium. In the case of perfectly competitive producers, there is no recognized interdependence among rivals and therefore no reaction by one producer to fluctuations in the output of another.

By comparing the comparative static properties of equilibrium output adjustments that emanate from different market structures, Smith (2004) demonstrates that differences in the frequency of compensating output changes are systematically related to the degree of interdependence among producers, which provides a means for distinguishing among competitive, oligopolistic, and collusive behavior.[20] To illustrate this approach, consider an industry consisting of N firms, each of which produces a homogeneous product subject to marginal cost:

$$mc_i(q_i) = a_i + b_i q_i, \tag{4}$$

where mc_i represents marginal cost of the i^{th} firm and q_i its output level, with $a_i > 0$, $b_i > 0$. I allow the a_i to vary randomly from period to period. Specifically, I assume that Δa_i has zero mean and finite variance, with $E[\Delta a_i \Delta a_j] = 0$ for all $j \neq i$. Variations in the a_i represent idiosyncratic shocks to the marginal cost functions of the several producers.[21]

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

$$Q_d(p) = D - p, \tag{5}$$

where without loss of generality I measure output in units such that the slope of the demand curve is –1. If all producers take price as given, first-order conditions for profit maximization require:

$$q_i(p) = (p - a_i)/b_i. \tag{6}$$

For convenience, I will assume that all b_i are identical, but this is not necessary for the results that follow. The total quantity supplied would then vary with price as:

20. Libecap and Smith (forthcoming) examine compensating production changes on the part of Saudi Arabia as part of a broader inquiry into governmental policies towards oil production, but they do not extend the concept to study behavior of the cartel as a whole, as is done here.

21. This specification is consistent with a broad variety of stochastic processes. For example, if one lets: $a_{i,t} = \rho a_{i,t-1} + \varepsilon_{i,t}$ for all i, where the $\varepsilon_{i,t}$ represent white noise, one has: $a_{i,t} = \sum_{\tau=1}^{t} \rho^{t-\tau} + \varepsilon_{i,\tau}$, which implies: $\Delta a_{i,t} = \varepsilon_{i,t} + (\rho - 1)\sum_{\tau=1}^{t} \varepsilon_\tau \rho^{t-\tau}$ $\forall i$ and t, which assures that the shocks are idiosyncratic. Thus, the present model spans the range from random walks (unit roots) to mean reversion.

$$Q_s(p) = \sum_{i=1}^{N} q_i(p) = \frac{Np}{b} - \frac{1}{b} \sum_{i=1}^{N} a_i. \tag{7}$$

Equating demand with supply yields the equilibrium price:

$$p^* = \frac{bD + \sum_{i=1}^{N} a_i}{b + N}. \tag{8}$$

Substituting p^* into Equation 6 determines the output of each producer:

$$q_i = \frac{bD - (b + N - 1)a_i + \sum_{j \neq i} a_j}{b(b + N)}. \tag{9}$$

The adjustment to output pursuant to any set of cost shocks is found by differencing:

$$\Delta q_i = -\frac{b + N - 1}{b(b + N)} \Delta a_i + \frac{1}{b(b + N)} \sum_{j \neq i} \Delta a_j. \tag{10}$$

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

$$[E\Delta q_i \Delta q_j] = -\sigma^2 \left[\frac{2(b + N - 1)}{b^2 (b + N)^2} - \frac{N - 2}{b^2 (b + N)^2}\right] = -\sigma^2 \frac{(2b + N)}{b^2 (b + N)^2}, \tag{11}$$

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:

$$[E\Delta q_i^2] = \sigma^2 \left[\frac{(b + N - 1)^2 + (N - 1)}{b^2 (b + N)^2}\right]. \tag{12}$$

The correlation between output adjustments of perfectly competitive producers is:

$$\rho_{perfcomp} = \frac{E[\Delta q_i \Delta q_j]}{\sqrt{E(\Delta q_i^2)E(\Delta q_j^2)}} = -\frac{2b + N}{(b + N - 1)^2 + (N - 1)}. \tag{13}$$

which 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 one assumes further that cost shocks are normally distributed, then the competitive benchmark can also be described in terms of θ, the probability of "compensating" output adjustments. 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:

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

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, 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.

Compensating Output Adjustments: Testable Hypotheses

By extending this type of analysis across a broad spectrum of market models, Smith (2004) derives a specific ordering in terms of the prevalence of compensating changes:

$$\rho_{cartel} < \rho_{be} < \rho_{stackelberg} < \rho_{cournot} < \rho_{perfcomp} \approx 0\%;$$

and

$$\theta_{cartel} > \theta_{be} > \theta_{stackelberg} > \theta_{cournot} > \theta_{perfcomp} \approx 50\%;$$

where ρ_x represents the output correlation and θ_x represents the probability of observing offsetting production changes among producers operating under the given market structures:

cartel: A frictionless association of producers acting essentially as a multi-plant monopoly; allocating output to equalize the marginal cost of each producer with marginal revenue of the cartel.

be: Bertrand-Edgeworth competition, in which rivals compete via pricing strategies that devolve in equilibrium to pricing at marginal cost.

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."

cournot: The standard Cournot model, in which it is assumed that each producer takes the output of rivals as given, then equates its own marginal cost to perceived marginal revenue.

perfcomp: The perfectly competitive benchmark, in which no firm is large enough to have a perceptible impact on market price, and all firms act as price-takers.

In addition to these implications of the traditional models of interdependent behavior, Smith (2004) proposes one further, perhaps more realistic, model of collusive conduct. In contrast to the frictionless cartel, envision a collusive syndicate of producers who operate under the weight of transactions costs, i.e., a "bureaucratic production syndicate." In this model, any difficulty in reaching consensus on proposed output revisions within the syndicate (and the profit redistributions that would result) constitutes 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 syndicate would be expected to change output allocations 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 compensating output changes are less prevalent than in the case of a frictionless cartel:

$$\rho_{cartel} < \rho_{bureaucracy}$$

and

$$\theta_{cartel} > \theta_{bureaucracy}$$

Where the bureaucratic syndicate might rank relative to the other forms of market conduct depends on the magnitude of transaction costs. If such costs are sufficiently large, it is possible that one could observe: $\rho_{bureaucracy} > 0$ and $\theta_{bureaucracy} < 50\%$. In other words, the bureaucratic syndicate is the only form of interdependent behavior reviewed here that could conceivably fall on the "other side" of the perfectly competitive benchmark.[22]

Casual observation suggests that, if OPEC does act as a cartel, then it must be of the second type. Production quotas are reviewed infrequently and changed only if relatively large shocks have disturbed the market during the interim.[23] Throughout the twenty years during which OPEC has assigned individual quotas to each member, revisions have occurred less than twice per year, on average.[24] 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.[25] This is a justifiable policy, of course, if the costs of adjustment threaten to outweigh the benefits.

Based on the preceding discussion, it is possible to rank at least some market structures in terms of the predicted frequency of compensating production changes. Here I put forth several testable hypotheses that are relevant to the OPEC debate:[26]

H_1: OPEC members exhibit compensating production changes (measured vs. the rest of OPEC) no less frequently than non-OPEC (i.e., competitive) producers (measured vs. the rest of non-OPEC output).

Rejection of H_1 would be inconsistent with the competitive, Cournot, Bertrand-Edgeworth, Stackelberg, and frictionless-cartel hypotheses. It would not be inconsistent with the bureaucratic–syndicate hypothesis, but it would be indicative that transactions costs within OPEC are relatively high.

H_2: OPEC members exhibit compensating production changes (measured vs. the rest of OPEC and vs. non-OPEC output) no less frequently since the formal quota system was adopted than before.

Rejection of H_2 would contradict the notion that introduction of the quota system has had no effect on the behavior of OPEC members,

22. Although it is well known that in games of repeated competition, a variety of different equilibria may exist for a given set of rivals, the present result would make it difficult to interpret a history of parallel action as the non-cooperative equilibrium to some stage game (e.g., Cournot, Stackelberg, etc.) in every period. See Phlips (1996, ch. 8) for more on the relationship between multiple equilibria in repeated games and the diagnosis of collusive action.

23. Production levels are known to deviate frequently from assigned quotas, however, and it is the data on actual production levels that I employ in subsequent testing. The transaction costs associated with quota revisions are nevertheless indicative of the type of transaction costs incurred when actual production levels change.

24. 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.

25. See, for example, "OPEC Sits Tight among Market-Share Thieves," *Petroleum Intelligence Weekly*, page 1, July 1, 2002.

26. It is possible to formulate analogous tests based on observed correlations among output changes. Because those tests are based on the same underlying data, they tend to give similar results.

and would indicate that the quota system has tended to increase transactions costs within the organization.

H_3: OPEC members exhibit compensating production changes measured vs. the rest of OPEC no less frequently than they do vs. the output of non-OPEC producers.

Rejection of H_3 would be inconsistent with the competitive hypothesis, but not necessarily inconsistent with the cartel or other oligopolistic hypotheses.

H_4: Saudi Arabia exhibits compensating production changes (vs. output from the rest of OPEC and from non-OPEC producers) no more frequently than do other OPEC members.

Rejection of H_4 would be inconsistent with the hypothesis that OPEC is an organization of equals always operating on a cooperative basis, and indicative of a special role (e.g., Stackelberg leader) played by the Saudis within OPEC.

IV. EMPIRICAL PROCEDURES AND RESULTS

Data:

The data employed to perform these tests 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 several other major non-OPEC producers. 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. For our purposes, the historical series are divided into "pre-quota" and "quota" periods. From January 1973 through March 1982, OPEC assigned no formal production quotas to individual members, relying instead on a system of posted prices that incorporated various differentials for quality, location, etc. The quota system was initiated in April 1982 and continues to the present.[27]

27. The line of demarcation separating "pre-quota" and "quota" intervals is only approximate due to variations across time and countries in how the quota has been construed and enforced. The Saudis, for example, initially refused to formally acknowledge a quota for themselves (1982-85), acting nominally as "swing producer" instead. Iraq has remained outside the quota system altogether since 1998. Despite aberrations like this, the procedural changes that were introduced in 1982 represent an important institutional change that might have altered behavior; and below I examine that contrast.

It is debatable whether analysis of monthly or quarterly production changes would provide a better test of our hypotheses. Monthly reporting probably captures more random demand and supply shocks. This is not necessarily a disadvantage since all producers (OPEC and non-OPEC) are buffeted by monthly shocks and our theory attempts to identify systematic differences in the way that potential rivals react to such shocks. Of course, monthly reporting also provides three times as many observations. On the other hand, quarterly figures might involve smaller *reporting* errors, which would reduce bias and enhance power. To be conservative, I report results based on both monthly and quarterly observations. In fact, the two sets of results are similar.

Output changes are measured as follows:

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

where *"i"* designates a specific producer or producer group and *"t"* designates the period for which production is reported. Producer i is counted as having exhibited a compensating change vs. reference group j in any period 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}:

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

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.

I look for systematic differences in these frequencies for different types of pairings; for example, when the frequency of compensating changes among OPEC members is compared to that among non-members; or when pre-quota OPEC behavior is compared to subsequent behavior. A simple F-test based on an ANOVA of observed frequencies would suffice, but for the apparent departure of the f_{ij} (which are proportions) from a normal distribution. A standard remedy is to fit the observed proportions to a logistic regression model of the form:

$$\text{In}\left[\frac{f_{ij}}{1-f_{ij}}\right] = \alpha + X_{ij}\beta + \varepsilon_{ij}, \tag{14}$$

where the X_{ij} are variables that identify the type of pairing (producer, reference group, quota, etc.) and the β are parameters that represent the hypothesized differences in behavior depending on these characteristics. Under standard assumptions regarding the ε_{ij}, one obtains unbiased and efficient estimates of β via Weighted Least Squares.

Estimation Results:

The data are summarized in Tables 1a (monthly observations) and 1b (quarterly observations). Each producer's behavior is tabulated according to time period (before and after quota) and reference group of other producers (OPEC and non-OPEC). Table entries record the percentage of total months (or quarters) in which compensating production changes are observed for the given pairing. For example, Indonesia's monthly production changes offset the change in the rest of OPEC 35.5% of the time prior to the implementation of OPEC's quota system, but only 27.0% of the time thereafter. The category "Rest of OPEC" consists of total OPEC production less the comparison country; i.e., total OPEC less Indonesia in the case just mentioned. The category "non-OPEC" output represents total world production net of OPEC and the production of any non-OPEC country involved in the comparison.

For non-OPEC producers, the entries in Tables 1a and 1b confirm our earlier conjecture: competitive producers exhibit compensating production changes roughly 50% of the time, as if the changes occurred by chance. This is true whether output variations of individual non-OPEC producers are being compared to variations from the rest of the non-OPEC world (the figures shown in Table 1), or simply to the production of other *individual* non-OPEC producers (not shown).

To determine whether behavior of OPEC members deviates significantly from that of non-OPEC (i.e., competitive) producers, I turn to the logistic regressions, which are summarized in Table 2. To capture all of the hypothesized effects (H_1-H_4), two versions of the model are estimated, and each version is estimated based on both monthly (panel a) and quarterly (panel b) observations. The following explanatory variables are used:

OPEC	=	1	if producer is OPEC member,
	=	0	otherwise.
Quota	=	1	if after March 1982 and producer is OPEC member,
	=	0	otherwise.
Saudi	=	1	if producer is Saudi Arabia,
	=	0	otherwise.
v NOPEC	=	1	if comparison is to non-OPEC production,
	=	0	otherwise.
Core	=	1	if producer is Kuwait, Saudi Arabia, or UAE,
	=	0	otherwise.

I begin with hypothesis H_1. On average over the entire period (pre- and post-quota), Table 1a (monthly data) showed that OPEC members exhibit compensating behavior vs. the rest of OPEC 33.0% of the time, whereas non-OPEC members exhibit compensating behavior vs. non-OPEC output more frequently, 45.8% of the time. The negative coefficient of "OPEC" in Model 1a (see Table 2) proves this difference to be highly significant (99% confidence, one-tailed test) based on the monthly data. Moreover, this result is confirmed by analysis of the quarterly data, where the t-statistic grows even larger (see Model 1b). I conclude that OPEC members have exhibited significantly less compensating behavior than their non-OPEC counterparts have. This constitutes a strong rejection of H_1, which implies also a strong rejection of the competitive, Cournot, Stackelberg, Bertrand-Edgeworth, and frictionless cartel models of OPEC behavior in favor of the bureaucratic-syndicate hypothesis.

The first model also permits a test of the impact of the quota system (hypothesis H_2). Because the quotas do not bind output of non-OPEC producers, the "Quota" variable is introduced as an interaction effect that applies only to OPEC members and only after the quota was introduced.[28] Based on monthly data (Model 1a), the estimated coefficient is significantly less than zero (95% confidence), meaning that compensating behavior among OPEC producers occurred less frequently after March 1982. In contrast, compensating behavior among the control group of non-OPEC producers hardly varies between periods, 45.2% before vs. 46.4% after (see Table 1a), which suggests that it was the quota system rather than changes in the broader market that tended to suppress compensating production changes within OPEC. Based on these results from the monthly data, H_2 would be rejected.

The quarterly data tell a somewhat different story about the quota. Based on Model 1b, the quota system appears to have had little or no effect on the frequency with which OPEC members offset variations from the rest of OPEC. As noted when testing H_1, less compensating behavior is seen among OPEC producers than among non-OPEC producers, but the magnitude of that difference is (according to the quarterly data) not affected by introduction of the quota. How to resolve the conflict between monthly and quarterly results? It may be that the quarterly data are freer of reporting errors and provide a more accurate picture. That interpretation will be challenged, however, by some further results I come to later. For the moment, the apparent contradiction must remain a puzzle.

I move now to the second model for a test of H_3, the hypothesis that OPEC producers offset (internal) changes in the output of the rest of OPEC no less frequently than they offset (external) changes in non-OPEC production. The monthly and quarterly data agree completely in this regard: hypothesis H_3 is strongly rejected, as indicated by the significant positive coefficients associated with the variable "v NOPEC" in Models 2a and 2b. Evidently, OPEC producers are much more likely to offset output changes that originate outside the group than those that come from within. This aspect of OPEC behavior is inconsistent with the competitive hypothesis, but entirely consistent with the behavior of a cartel that incurs relatively high transaction costs whenever market shares shift.

28. When a separate term is introduced in the equation to show the response of non-OPEC producers to the quota, it is indistinguishable from zero.

The second model also revisits the impact of the quota system, this time weighing both internal and external adjustments together: OPEC producers became significantly less likely to offset production changes (whether emanating from within or without) after quotas were introduced. This is demonstrated by the highly significant (99% confidence) negative coefficients on the "Quota" variables in Models 2a and 2b. It may be possible, through more extensive use of dummy variables and further partitioning of the sample period, to more clearly identify the impact of the quota system. A case in point is Iraq, which has been exempt from the quota system since July 1998. Before becoming exempt, Iraq exhibited compensating changes relative to the rest of OPEC 30.8% of the time, but since the exemption this has risen to 50%—virtually indistinguishable from the group of non-OPEC producers, who are of course also exempt from quotas.

On balance, the evidence regarding the quota system strongly suggests that it has had the effect of increasing transaction costs—perhaps more so for certain types of production adjustments than others. But, the finding of increased transactions cost should not come as a surprise, even for those who would expect formalization of this control device to enhance cartel operations. It hardly seems implausible that the process of reaching consensus becomes more problematic once each member's stake in the outcome has to be set forth explicitly and mutually agreed.

There are certain indications in the raw data (see Tables 1a and 1b) that Saudi Arabia may have played a special role within OPEC, contrary to hypothesis H_4. Unlike the rest of OPEC, for example, the Saudis actually *increased* the frequency of compensating production changes after quotas were introduced, whether measured by monthly or quarterly data. That is what one would have expected to observe if, as announced at the time the quota system was adopted in 1982, the Kingdom in fact assumed a more deliberate role as swing producer. However, the statistical evidence to support this view is weak, and on this point the results from monthly and quarterly data again coincide. The variable that distinguishes Saudi behavior from other OPEC producers in Models 2a and 2b is not significantly different from zero in either equation.[29] Although the sign of the coefficient would tend to refute H_4, the lack of significance undermines support for the proposition that the Saudis have played a special role. The data are simply inconclusive on this point; Saudi leadership is not ruled out, nor ruled in. If the Kingdom has assumed the role of Stackelberg leader, dominant firm, or swing producer, it must not have been pursued with enough vigor and continuity, either

29. There is no appreciable change in the coefficients of these equations or their significance levels when the outputs of non-Saudi members are compared to the rest of non-Saudi-OPEC. Moreover, when the Saudi dummy variable is dropped from the equation, the results are again essentially unchanged.

before or after the quota system was adopted, to have left a discernable pattern in the data.[30]

There is somewhat more support for the hypothesis that a small group of producers may have served collectively as "swing" producer, as indicated by the regression results for Models 3a and 3b. These regressions replicate the structure of Models 2a and 2b, except the definition of swing producer is expanded to include Kuwait and the UAE, in addition to Saudi Arabia. Based on monthly data (Model 3a), this group exhibits significantly more compensating production behavior than the rest of OPEC. Based on quarterly data (Model 3b), this distinction is not so clear.

V. SUMMARY AND CONCLUSIONS

Despite a strong consensus among experts and laymen alike that OPEC operates as a cartel, very little conclusive statistical evidence of collusive behavior has appeared in the economics literature to date. The statistical ambiguity undoubtedly stems from many factors, some of which may be further compounded as events in the world oil market continue to unfold. One point seems clear, however: empirical research has been inconclusive in part due to the relatively low power of statistical tests employed.

Pricing-based tests of market structure are, at least concerning the world oil market, inherently difficult because they must overcome a relatively high degree of uncertainty regarding the magnitude of marginal costs and the structure of demand, and they are complicated by the necessity of distinguishing Ricardian rents (and perhaps user costs) from monopoly profits. In contrast, I have examined predicted production behavior using tests that are largely invariant with respect to unknown values of these background parameters. When these tests are applied to the members of OPEC and their rivals, the results are quite clear: OPEC is much more than a non-cooperative oligopoly, but less than a frictionless cartel (i.e., multi-plant monopoly). 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 syndicate; i.e., a cartel weighed down by the cost of forging and enforcing consensus among its members, and therefore partially impaired in pursuit of the common good.

The evidence also suggests that OPEC's formal quota system, introduced in 1982 to replace the old posted-price scheme, has increased transactions costs

30. Some ambiguity exists in the literature regarding the terms "swing producer" and "residual supplier." These are often construed to mean that one producer offsets variations in the output of others to whatever extent may be needed to "defend" a pre-determined price level. In this sense, a profit-maximizing dominant firm is not a swing producer because its optimal price varies with the production levels adopted by the others. A swing producer or residual supplier, defined as above, should exhibit compensating production changes more often than a dominant firm or Stackelberg leader, since the response of the swing producer to fluctuations in output of the fringe is not damped by the countervailing change in optimal price.

within the organization and pushed behavior further away from the ideal of a pure and frictionless cartel. Whether that also means that the quota system failed to enhance the performance of the cartel is unclear. There is only weak evidence to indicate that Saudi Arabia has acted as a "leader" or dominant firm within the cartel, although that possibility cannot be formally rejected. If the Saudis have performed such a role, then at least one can say that it has not been executed with sufficient vigor or consistency to be clearly discernable in the data. The evidence is more supportive, but still mixed, of the possibility that a "core" group of producers (including Kuwait, Saudi Arabia, and the UAE) have acted collectively as a swing producer to offset production fluctuations arising from other OPEC members as well as non-OPEC producers.

This paper has examined the conduct of members of an alleged cartel, not the performance of the cartel itself. Any conclusions regarding the effectiveness of OPEC's cooperative actions, or the organization's impact on market prices and member profits, are beyond the scope of this research. A cartel's actions may be in vain if it lacks either the information base to anticipate, or the operating flexibility to respond to market forces. Whether the rewards reaped by OPEC have actually gone beyond what one could expect of a non-cooperative oligopoly is not clear. That part of the question remains.

REFERENCES

Adelman, M. A. (1980). "The Clumsy Cartel," *The Energy Journal*, vol. 1, no. 1, pp. 43-53.

Adelman, M. A. (1982). "OPEC as a Cartel," in *OPEC Behavior and World Oil Prices,* J. Griffin and D. Teece, eds., London: Allen & Unwin, pp. 37-57.

Adelman, M. A. (1992). "Finding and Development Costs in the United States, 1945-86," in J. R. Moroney, ed., *Advances in the Economics of Energy and Resources,* vol. 7, Greenwich, CT: JAI Press.

Adelman, M. A. (1995). *The Genie Out of the Bottle,* Cambridge, MA: MIT Press.

Adelman, M. A. (2002). "World Oil Production and Prices: 1947-2000," in *Oil and the Economy: Recent Experience in Historical Perspective,* James L. Smith, ed., (*Quarterly Review of Economics and Finance,* vol. 42, no. 2), pp. 169-191.

Adelman, M.A., and Manoj Shahi (1989). "Oil Development-Operating Cost Estimates, 1955-85," *Energy Economics,* vol. 11, pp. 2-10.

Alhajji, A. F., and David Huettner (2000a). "The Target Revenue Model and the World Oil Market: Empirical Evidence from 1971 to 1994," *The Energy Journal,* vol. 21, no. 2, pp. 121-143.

Alhajji, A. F., and David Huettner (2000b). "OPEC and World Crude Oil Markets from 1973 to 1994: Cartel, Oligopoly, or Competitive?" *The Energy Journal,* vol. 21, no. 3, pp. 31-60.

Amuzegar, Jahangir (1999). *Managing the Oil Wealth: OPEC's Windfalls and Pitfalls,* London: I.B. Tauris Publishers.

Claes, Dag Harald (2001). *The Politics of Oil-Producer Cooperation*, Boulder, CO: Westview Press.

Dahl, Carol and Mine Yücel (1991). "Testing Alternative Hypotheses of Oil Producer Behavior," *The Energy Journal,* vol. 12, no. 4, pp. 117-138.

Gately, Dermot (1984). "A Ten-Year Retrospective: OPEC and the World Oil Market," *Journal of Economic Literature,* vol. 22, pp. 1100-1114.

Gault, John, Charles Spierer, Jean-Luc Bertholet, and Bahman Karbassioun (1999), "How Does OPEC Allocate Quotas?" *Journal of Energy Finance & Development,* vol. 4, no. 2, pp. 137-148.

Geroski, P. A., A. M. Ulph, and D. T. Ulph (1987). "A Model of the Crude Oil Market in which Market Conduct Varies," *The Economic Journal,* vol. 97 (Conference), pp. 77-86.

Green, David Jay (1988). "The World Oil Market: An Examination Using Small-Scale Models," *The Energy Journal,* vol. 9, no. 3, pp. 61-77.

Griffin, James M. (1985). "OPEC Behavior: A Test of Alternative Hypotheses," *American Economic Review,* vol. 75, no. 5, pp. 954-963.

Griffin, James M., and William S. Nielson (1994). "The 1985-86 Oil Price Collapse and Afterwards: What Does Game Theory Add?" *Economic Inquiry,* vol. 32, pp. 543-561.

Gülen, S. Gürcan (1996). "Is OPEC a Cartel? Evidence from Cointegration and Causality Tests," *The Energy Journal,* vol. 17, no. 2, pp. 43-57.

Harstad, Ronald M., and Louis Phlips (1994) "Informational Requirements of Collusion Detection: Simple Seasonal Markets," mimeo, European University Institute, Florence (reproduced as ch. 8 in *Competition Policy: A Game-Theoretic Perspective,* by Louis Phlips, Cambridge University Press, 1995).

International Petroleum Monthly (2002). US Energy Information Administration, Washington, DC (various issues).

Jones, Clifton T. (1990). "OPEC Behavior under Falling Prices: Implications for Cartel Stability," *The Energy Journal,* vol. 11, no. 3, pp. 117-129.

Kohl, Wilfrid L. (2002). "OPEC Behavior, 1998-2001," in *Oil and the Economy: Recent Experience in Historical Perspective,* James L. Smith, ed., (*Quarterly Review of Economics and Finance,* vol. 42, no. 2), pp. 209-233.

Libecap, Gary D. (1989). "The Political Economy of Crude Oil Cartelization in the United States, 1933-1972," *The Journal of Economic History,* vol. 49, no. 4, pp. 833-855.

Libecap, Gary D. and James L. Smith (2004). "Political Constraints on Government Cartelization: The Case of Oil Production Regulation in Texas and Saudi Arabia," in *How Cartels Endure and How They Fail: Studies of Industrial Collusion,* Peter Grossman, ed., Cheltenham, UK: Edward Elgar Publishing Ltd.

Loderer, Claudio (1985). "A Test of the OPEC Cartel Hypothesis: 1974-1983," *Journal of Finance,* vol. 40, no. 3, pp. 991-1008.

Mabro, Robert (1998). "OPEC Behaviour 1960-1998: A Review of the Literature," *Journal of Energy Literature,* vol. 4, no. 1, pp. 3-27.

Mitchell, John, et. al. (2001). *The New Economy of Oil,* London: Royal Institute of International Affairs.

Oil and Gas Journal Energy Database (2002). PennWell Corporation, Tulsa, OK.

Oil Market Intelligence (2002). Energy Intelligence Group, New York, NY (various issues).

Parra, Francisco (2004). *Oil Politics: A Modern History of Petroleum,* London: I. B. Tauris Publishers.

Petroleum Intelligence Weekly (2002). Energy Intelligence Group, New York, NY (various issues).

Phlips, Louis (1996). "On the Detection of Collusion and Predation," *European Economic Review,* vol. 40, pp. 495-510.

Ramcharran, Harri (2002). "Oil Production Responses to Price Changes: An Empirical Application of the Competitive Model to OPEC and non-OPEC Countries," *Energy Economics,* vol. 24, no. 2, pp. 97-106.

Smith, James L. (2004). "Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis," *Proceedings of the North American Conference of the International Association for Energy Economics,* Washington DC, July 8-10, 2004.

Spilimbergo, Antonio (2001). "Testing the Hypothesis of Collusive Behavior Among OPEC Members," *Energy Economics,* vol. 23, pp. 339-353.

Stigler, George (1964). "A Theory of Oligopoly," *Journal of Political Economy,* vol. 72, no. 2, pp. 44-61.

Watkins, G. Campbell, and Shane S. Streifel (1998). "World Crude Oil Supply: Evidence from Estimating Supply Functions by Country," *Journal of Energy Finance and Development,* vol. 3, no. 1, pp. 23-48.

Figure 1a. Power Function, 5% significance level

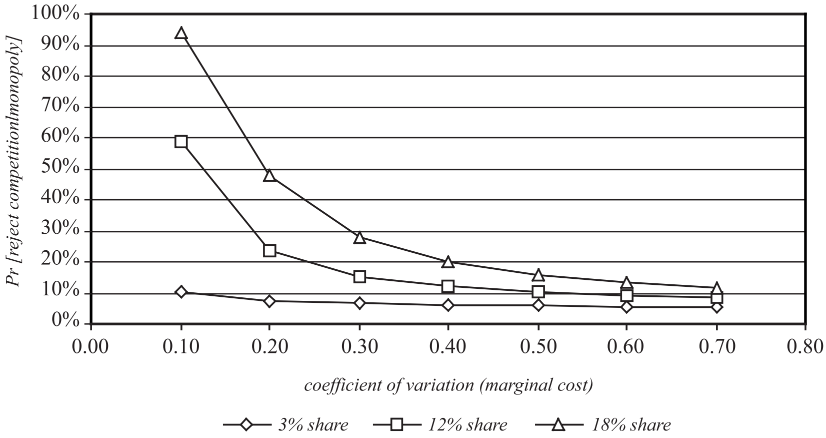

Figure 1b. Power Function, 1% significance level

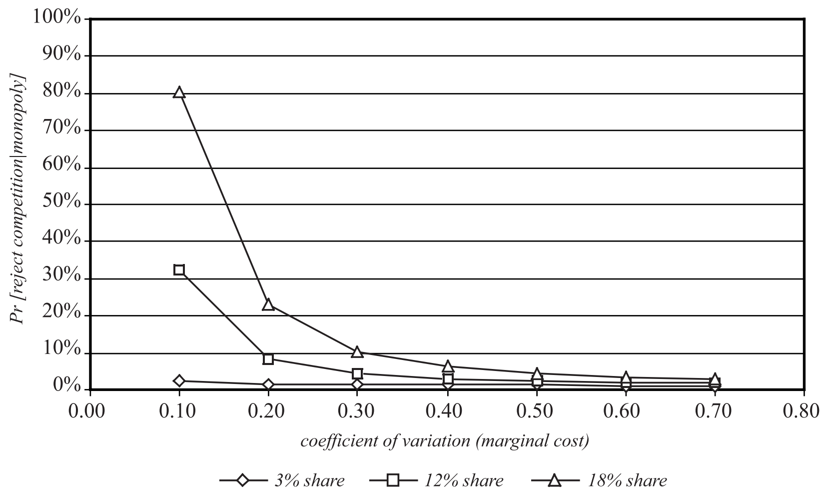

Table 1a. Frequency of compensating production changes (Monthly Observations)

	vs. Rest of OPEC*			vs. non-OPEC*		
Country	*pre-quota*	*quota*	*overall*	*pre-quota*	*quota*	*overall*
Algeria	17.3%	16.0%	16.7%	19.1%	15.6%	17.4%
Indonesia	35.5%	27.0%	31.3%	47.3%	31.2%	39.3%
Iran	33.6%	37.1%	35.4%	39.1%	38.0%	38.6%
Iraq	35.5%	31.6%	33.6%	30.9%	36.7%	33.8%
Kuwait	36.4%	33.3%	34.9%	42.7%	41.4%	42.1%
Libya	40.0%	17.3%	28.7%	49.1%	18.1%	33.6%
Nigeria	41.8%	35.9%	38.9%	49.1%	41.8%	45.5%
Qatar	42.7%	26.6%	34.7%	44.5%	32.5%	38.5%
UAE	44.5%	27.8%	36.2%	50.9%	36.3%	43.6%
Venezuela	46.4%	28.7%	37.6%	50.9%	28.7%	39.8%
Saudi Arabia	33.6%	37.1%	35.4%	36.4%	43.9%	40.2%
OPEC average	37.0%	28.9%	33.0%	41.8%	33.1%	37.5%
Canada				50.9%	51.9%	51.4%
Mexico				37.3%	49.4%	43.4%
Norway				50.9%	39.7%	45.3%
Russia				48.2%	43.0%	45.6%
UK				32.7%	44.7%	38.7%
US				50.9%	49.8%	50.4%
Non-OPEC avg.				45.2%	46.4%	45.8%

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

Table 1b. Frequency of compensating production changes (Quarterly Observations)

	*vs. Rest of OPEC**			*vs. non-OPEC**		
Country	*pre-quota*	*quota*	*overall*	*pre-quota*	*quota*	*overall*
Algeria	25.0%	21.5%	23.3%	50.0%	30.4%	40.2%
Indonesia	41.7%	38.0%	39.9%	47.2%	48.1%	47.7%
Iran	33.3%	35.4%	34.4%	55.6%	39.2%	47.4%
Iraq	33.3%	34.2%	33.8%	38.9%	22.8%	30.9%
Kuwait	22.2%	35.4%	28.8%	55.6%	40.5%	48.1%
Libya	36.1%	22.8%	29.5%	58.3%	35.4%	46.9%
Nigeria	38.9%	36.7%	37.8%	47.2%	41.8%	44.5%
Qatar	38.9%	32.9%	35.9%	55.6%	34.2%	44.9%
UAE	22.2%	32.9%	27.6%	50.0%	43.0%	46.5%
Venezuela	41.7%	36.7%	39.2%	58.3%	35.4%	46.9%
Saudi Arabia	33.3%	35.4%	34.4%	41.7%	43.0%	42.4%
OPEC average	33.3%	32.9%	33.1%	50.8%	37.6%	44.2%
Canada				63.9%	55.7%	59.8%
Mexico				33.3%	48.1%	40.7%
Norway				47.2%	39.2%	43.2%
Russia				19.4%	39.2%	29.3%
UK				61.1%	38.0%	49.6%
US				50.0%	55.7%	52.9%
Non-OPEC avg.				45.8%	46.0%	45.9%

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

Table 2. Estimated logistic equations (Absolute value of asymptotic t-statistics in parens)

Model/Sample	*constant*	*OPEC*	*Quota*	*Saudi*	*Core*[3]	*v NOPEC*	R^2	*N*
A. Monthly Observations								
Model 1a: Like vs. Like[1]	-0.156	-0.402	-0.041				0.50	34
	(1.80)	(2.75)	(1.96)					
Model 2a: OPEC vs. All[2]	-0.528		-0.364	0.221		0.205	0.31	44
	(4.66)		(3.07)	(1.18)		(1.82)		
Model 3a: OPEC vs. All[2]	-0.571		-0.365		0.227	0.203	0.34	44
	(5.01)		(3.16)		(1.89)	(1.85)		
B. Quarterly Observations								
Model/Sample	*constant*	*OPEC*	*Quota*	*Saudi*	*Core*[3]	*v NOPEC*	R^2	*N*
Model 1b: Like vs. Like[1]	-0.148	-0.551	0.003				0.35	34
	(1.50)	(3.29)	(0.07)					
Model 2b: OPEC vs. All[2]	-0.498		-0.288	0.049		0.366	0.45	44
	(5.17)		(2.90)	(0.31)		(3.96)		
Model 3b: OPEC vs. All[2]	-0.504		-0.289		0.042	0.365	0.45	44
	(5.11)		(2.91)		(0.41)	(3.95)		

1 Sample: Each of eleven OPEC members vs. output from the rest of OPEC, and each of six non-OPEC producers vs. output from the rest of non-OPEC; before and after the quota was introduced

2 Sample: Each of eleven OPEC members vs. output from rest of OPEC and vs. output from non-OPEC; before and after the quota was introduced.

3 Core: Kuwait, Saudi Arabia, and the United Arab Emirates.

APPENDIX

1. The Precision of Marginal Cost Estimates

Adelman and Shahi (1989) estimate development and operating cost ($/barrel) on an annual basis over the interval 1970-85 for each OPEC member country.[31] In fact, they provide two figures, one estimate adjusted for the prevalence of offshore operations in each country (see their Table 10.5) and one estimate unadjusted by this factor (Table 10.4). The estimates for each country vary from year to year, substantially in some cases. As Adelman and Shahi point out, annual variations may be due in part to the phenomenon of reservoir depletion and in part to innovations in technology. Another source of variation comes simply from the random fluctuations in drilling results, expenditure levels, factor prices, reporting methods and classification errors, etc. that enter each year, directly or indirectly, into the cost estimation process.

To assess the magnitude of these random factors, I proceed as follows. The true marginal cost of development for a given country is unobservable, but may be assumed to vary smoothly from year to year, following a quadratic function over the period 1970-85. The quadratic form is general enough to permit rising, then falling costs if technological progress is sufficient to overcome the effects of depletion, or vice versa. After fitting the annual Adelman-Shahi cost estimates to a quadratic function, country-by-country, the "residuals" serve as a proxy for the random sources of variation. Based on these residuals, there are two ways to estimate the coefficient of variation: (1) after converting the residual errors to percentage terms, then calculate the standard deviation of the errors over the sample period, or (2) divide the standard error of the estimated equation by the average cost for the whole period. The second method produces a smaller estimate of the coefficient of variation in this instance, and to be conservative in my own argument I report only those results here.

Table A1 shows the estimated coefficient of variation for each country, based on Adelman and Shahi's "unadjusted" cost estimates as well as the "adjusted" cost estimates.[32] For the fifteen OPEC regions taken together, the coefficient of variation ranges between 21% and 174%. The various ways of taking an average center approximately around 50%.

31. Adelman and Shahi also provide estimates for some prior years, but the coverage is sketchy prior to 1970.

32. To be conservative, I have thrown out the Ecuadorian cost estimates for 1970 and 1971 because they are rather spectacular outliers that would have substantially inflated the estimated coefficient of variation.

Table A1. Coefficients of variation

Region	*standard error / mean cost* *"unadjusted"*	*"adjusted"*
Venezuela	21%	35%
Nigeria	58%	58%
Libya	93%	89%
Indonesia	78%	74%
Gabon	27%	28%
Ecuador*	100%	113%
Saudi Arabia	44%	31%
Qatar	49%	46%
Neutral Zone	59%	61%
Kuwait	103%	91%
Iraq	174%	43%
Iran	26%	25%
Algeria	27%	43%
Dubai	38%	35%
Abu Dhabi	43%	45%
Simple Average	63%	54%
Weighted Average**	60%	46%

*1970 and 1971 cost estimates excluded. See text

**Weights based on 2002 Q2 production levels, as reported by Energy Intelligence Group, *Oil Market Intelligence, August 2002.*

MIT CENTER FOR ENERGY AND ENVIRONMENTAL POLICY RESEARCH REPRINT SERIES

CEEPR Reprints are available free of charge (limited quantities.) Order from MIT Center for Energy and Environmental Policy Research, E40-428, Cambridge, MA 02139-4307.

162. World oil production & prices 1947-2000, M. A. Adelman, *The Quarterly Review of Economics and Finance,* Vol. 42, pp. 169-191, (2002).
163. A Market-Based Environmental Policy Experiment in Chile, Juan-Pablo Montero, Jose Miguel Sanchez, and Ricardo Katz, *The Journal of Law and Economics,* Vol. XLV, No. 1, pp. 267-287, (April 2002).
164. Optimal timing problems in environmental economics, Robert S. Pindyck, *Journal of Economic Dynamics & Control*, Vol. 26, pp. 1677-1697, (2002).
165. Permits, Standards, and Technology Innovation, Juan-Pablo Montero, *Journal of Environmental Economics and Management,* Vol. 44, pp. 23-44, (2002).
166. Trading Programs for Environmental Management: Reflections on the Air and Water Experiences, Leonard Shabman, Kurt Stephenson, William Shobe, *Environmental Practice*, Vol. 4, pp. 153-162, (2002).
167. A Quantitative Analysis of Pricing Behavior in California's Wholesale Electricity Market During Summer 2000, Paul L. Joskow and Edward Kahn, *The Energy Journal*, Vol. 23, No. 4, pp. 1-35, (2002).
168. Prices versus quantities with incomplete enforcement, Juan-Pablo Montero, *Journal of Public Economics*, Vol. 85, pp. 435-454, (2002).
169. Emissions Trading in the U.S.: Experience, Lessons, and Considerations for Greenhouse Gases,A. Denny Ellerman and Paul L. Joskow,*Pew Center on Global Climate Change*, May 2003
170. Energy Policies and Their Consequences After 25 Years, Paul L. Joskow, *The Energy Journal*, Vol. 24, No.4, pp. 17-49, (2003)
171. The Real Oil Problem, M. A. Adelman, *Regulation*, Vol. 27, No. 1, pp. 16-21, (2004)
172. Volatility in Natural Gas and Oil Markets, Robert S. Pindyck, *The Journal of Energy and Development*, Vol. 30, No. 1, (2004)
173. Costs of Aggregate Hydrocarbon Additions, M.A. Adelman and G. Campbell Watkins, *The Energy Journal*, Vol. 25, No. 3, (2004)
174. Transmission policy in the United States, Paul L. Joskow, *Utilities Policy*, Vol. 13, pp. 95-115 (2005)
175. A Note on Tradeable Permits, A. Denny Ellerman, *Environmental & Resource Economics* 31: 123-131 (2005)
176. Merchant Transmission Investment, Paul Joskow and Jean Tirole, *The Journal of Industrial Economics*, Volume LIII, No. 2, (June 2005)
177. Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis, James L. Smith, *The Energy Journal,* Vol. 26, No. 1. (2005)