A statistical analysis of OPEC quota violations

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This paper is dedicated to my parents.

Abstract

This paper studies deviation from quotas in OPEC member countries from 1982 to 2001. GLS regressions are used to model percentage deviation as a linear function of eight market-based and country-specific variables. Model specifications include panel data, panel data with dummy variables, and individual country regressions. In the first two models, oil price, overall quota level and a member's quota as percentage of the total have a significant and negative effect on overproduction. Petroleum exports as percentage of total exports has a significant and positive effect. In the third model, only total quota and quota percentage are found to be significant.

1. Introduction

Conventional wisdom in the United States, and indeed in most of the West, holds that the Organization of Petroleum Exporting Countries is a monolithic if not monopolistic force in the international oil market. Public officials from major parties frequently argue that OPEC's unity is the principal cause of high gasoline prices. In June 2002, for instance, Rep. Henry Hyde declared at a committee hearing that "OPEC… conspires to fix prices and restrict the supply of crude oil to the world market in order to maximize profits."[1] Even policymakers who encourage constructive cooperation with OPEC implicitly agree with the notion that the cartel speaks with one voice and acts in a cohesive manner. This, at least, is the accepted presumption. The reality, as we shall see, is far different.

There are multiple reasons for OPEC's disarray over the past two decades, ranging from divergent geopolitical considerations to conflicting economic interests among its eleven members. There are also multiple manifestations of this disarray. This paper, however, will focus on what is perhaps the most important measure – at least from an economic standpoint – of structural weakness within OPEC. The most persistent feature of the cartel's behavior since it implemented a quota mechanism has been non-compliance by its members with mutually set output limits. Chronic overproduction, while naturally beneficial for oil-consuming nations, represents a severe challenge for OPEC to overcome.

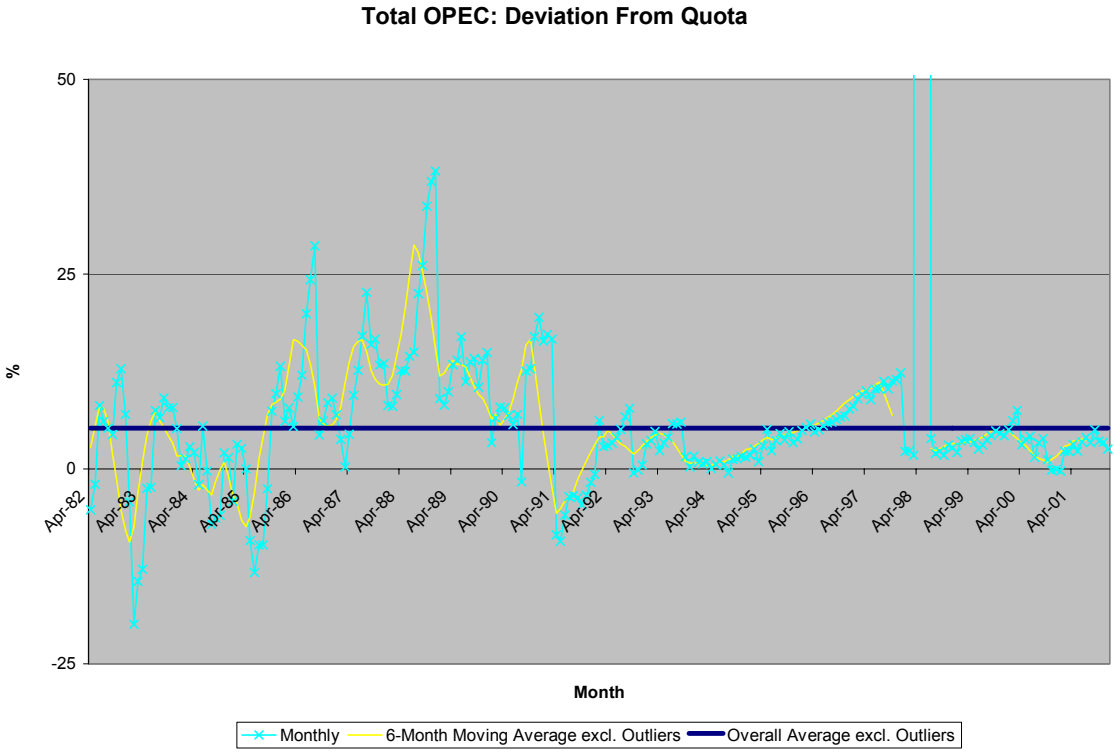
The methodology of this paper is to first explore the history of quota violations within OPEC, using both consolidated and individual member statistics. This is followed by a review of recent literature that attempts to explain and model overproduction as a rational economic strategy. I then attempt to develop a thorough econometric model with adequate predictive power that analyzes the effect of common oil market influences and national macroeconomic indicators on the level of quota-breaking. The ultimate objective of this paper is to identify the relevant economic factors behind quota-breaking in order to enhance overall understanding of OPEC's standing in the petroleum market. Given the importance of this organization – partly actual, partly perceived – for macroeconomic stability, such analysis is vital from a public policy standpoint. I hope that this paper will contribute to a more accurate understanding among oil-consuming nations of the world's most famous cartel.

2. Historical Background

It is necessary to establish a formal conception of quota violations before proceeding. Because output varies from country to country, any useful definition must 'normalize' divergence from quotas to take this fact into account. This means that nominal terms (e.g., number of barrels) are not appropriate measures. A highly intuitive definition is adopted by Dahmani and Al-Osaimy, who define deviation from the official quota as the "ratio of the difference between the production and the quota [of a single member] to the quota" over a period of time.[2] (For two or more countries, an appropriate summation is added). This is then multiplied by 100 to arrive at a percentage deviation. That is: $D = (P_t - Q_t) / Q_t * 100$.[3] A positive value given by this formula represents production above the allotted quota, while a negative value signifies underproduction. When the formula is applied to a period of two or more months, it yields a mean deviation that is weighted by each month's level of output.

Data regarding member quotas – formally termed "production ceilings" – is publicly available in the OPEC Secretariat's Annual Statistical Bulletin, the 2001 edition of which is the most recent available.[4] The time series dates back to April 1982, prior to which time OPEC did not maintain a formal quota policy. Actual production data for every member, on a monthly basis, is collected by the U.S. Energy Information Administration.[†] This data for all eleven members is consolidated using the method described above and shown in Figure 1, along with a six-month moving average and an overall mean for the entire period until December 2001.[‡] (The analogous chart for individual members is included in the appendix).

Figure 1



[†] I thank James Williams of WTRG Economics for providing an edited version of the EIA time series for each member country. For a discussion of an important adjustment to EIA data, please see Appendix A.

[‡] Iraq data after July 1990 is excluded from all calculations due to the Gulf War, subsequent UN sanctions and withdrawal of the country from OPEC decision-making. (Source: OPEC) Gabon and Ecuador data is also excluded.

As Figure 1 indicates, cartel overproduction was frequent, though inconsistent and highly volatile. Both its absolute level and its volatility decreased markedly since the conclusion of the first Gulf War, before peaking in April-June 1998. This three-month period, when overproduction reached a staggering 2,000%, encompasses "temporary production cuts" imposed by the cartel.[5] This decision was pushed through by Saudi Arabia and other Gulf producers in the face of the Asian financial crisis and the associated global economic weakness.[6] While the policy called for across-the-board output reductions of over 90%, actual output remained nearly constant, as members – even those that advocated the curbs – largely ignored them. Though there have been considerable shifts in production allocations among members, overall quotas have not exhibited such sharp and sudden changes aside from this unusual period. These three months represent the only outliers in the entire time series and will be excluded from regressions.

Table 1: Total OPEC Summary Statistics, 1982-2001

	Mean Deviation from Quota (%)	Median Deviation from Quota (%)	Overproducing Months (%)
4/82 – 3/91	7.81	7.86	81.48
4/82 – 9/85	-0.24	0.85	54.76
10/85 – 3/91	12.74	12.55	98.48
4/91 – 12/01	6.22	3.60	91.80
Excl. outliers	3.60	3.50	91.60
4/91 – 12/95	1.90	2.43	86.00
1/96 – 6/98	18.71	7.87	100.00
Excl. outliers	7.34	6.80	100.00
7/98 – 12/01	3.15	3.40	92.86
Overall	6.85	4.39	86.96
Excl. outliers	5.26	4.30	86.78

Sources: EIA, OPEC

For purposes of analysis, we can divide the 230-month period into two major periods and a total of five sub-periods, listed in Table 1. From the beginning of the quota system until the conclusion of the Gulf War, mean overproduction was 7.81%, slightly higher than the overall mean. However, the 1982-85 period was actually characterized by output below quota – the only such extended period in the entire time series – but this was negated by high quota-breaking in

the later years of the decade, following "the collapse of oil prices in 1986."[7] After the war and associated economic dislocation in several member states, there was an extended period of high compliance until 1996; mean overproduction was a mere 1.90%. The worst level of quota-breaking took place between 1996 and mid-1998, though it should be noted that over half the overproduction in this period occurred during the three outlier months in 1998. A relatively high level of compliance was then restored until December 2001. Overall, OPEC overproduced more than four-fifths of the time since 1982, at an average of 6.85% above quota.

Interestingly, the right column in the table shows that the percentage of months in which OPEC overproduced remained largely constant over time, mostly in the 85%-95% range. While it increased slightly in the 1990's, far lower variability of overproduction (once outliers are disregarded) apparently contributed to better overall compliance. It is important to recognize that a modest level of overproduction can result from technical features of pipelines and not necessarily a policy shift by oil ministries in member states. As Dahmani and Al-Osaimy note, "the implementation of a [quota] decision… is rarely adhered to one hundred per cent."[8]

Table 2: Mean Percentage Deviation from Quota, 1982-2001

	4/82 – 3/91	4/91 – 12/01 Excl. outliers	Overall Excl. outliers
Algeria	-2.79	3.52	0.66
Indonesia	-1.62	1.41	0.00
Iran	3.35	2.48	2.81
Iraq	16.08	N/A	N/A
Kuwait	21.12	0.41	7.41
Libya	11.51	2.54	6.18
Nigeria	7.25	4.61	5.65
Qatar	10.71	14.29	12.95
Saudi Arabia	1.75	2.95	2.52
UAE	37.59	1.11	12.16
Venezuela	7.14	10.70	9.37
Sources: EIA, OPEC			

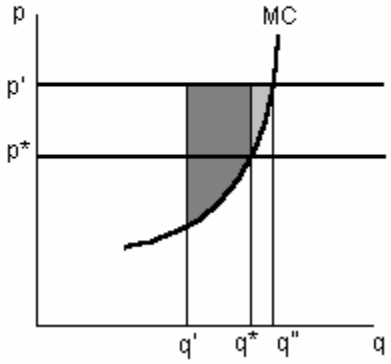
Using Table 2, we can identify the worst culprits among OPEC members in terms of percentage overproduction. For brevity, only average deviation is shown for each member. The

tiny yet wealthy Gulf sheikdoms of Qatar and the United Arab Emirates stand out as the only members whose overall 1982-2001 output exceeded their cumulative quotas by more than 10%. In fact, their level of overproduction is nearly twice the cartel average. In the first period, UAE had the worst level of compliance with 37.59% overproduction; Qatar assumed this role in the second period with 14.29%. Unlike Qatar, however, whose quota-breaking actually intensified with time, UAE improved its compliance dramatically in the 1990's.

Indonesia was the only member whose overall 20-year output did not exceed its quota, and, along with Algeria, one of two which underproduced in the 1980's. Both countries, in fact, have many opposing characteristics when compared with the two worst offenders. Their locations put them on OPEC's periphery, and in terms of GDP per capita, they are the second and fourth poorest members.[9] Saudi Arabia and Iran also demonstrated a consistently high level of compliance, with overall output 2.52% and 2.81% above quota, respectively.

3. The Nature of Overproduction

Figure 2 - Basic I/O Model of a Cartel
(Adapted from Hirshleifer and Hirshleifer pg. 249)



Having discussed the nature and extent of quota-breaking over the last two decades, I now turn to a discussion of factors that contribute to it. In principle, there are two sets of factors: common features of the international oil market and country-specific characteristics. Before

discussing them, it is vital to understand the economic incentive each OPEC member has to overproduce. We assume that the cartel seeks to raise the market price from p*, the equilibrium price under perfect competition, to p'. This is accomplished by agreeing to limit output, and for the hypothetical member depicted in Figure 2, output is cut from q* to q'. If it decides to produce beyond q', it alone will gain the revenue from additional quantity sold (shown as the darkly shaded area), while all of the cartel's members will suffer from a lower market price.[10] In short, overproduction is an example of concentrated benefits and distributed costs.

Basic game theory states that in the absence of an enforcement mechanism, the incentive described above will lead to endemic overproduction in a cartel. OPEC has never had a formal enforcement mechanism, and its structure prevents one from arising. The OPEC Statute asserts that "Member Countries shall fulfill, in good faith, the obligations assumed by them," but it also refers to members' "sovereign equality."[11] In practice, this means that collective decisions, though binding, are not backed by any disciplinary action, such as suspension of membership. A weak Ministerial Executive Council that nominally monitors output was nearly vetoed when its establishment was first proposed in 1984, on the basis that it would be "impinging to some extent on national sovereignty," despite its obvious value for cartel cohesion.[12]

Instead, Saudi Arabia has generally – though not always – assumed the self-declared role of cartel "enforcer."[13] It has both the willingness and the ability to rapidly boost output in the face of substantial overproduction by fellow members, precipitating a global supply glut and price collapse. Griffin and Xiong differentiate strongly between the production strategies of Saudi Arabia and those of smaller producers. They argue that the cartel's leading member has followed a "tit for tat strategy" since 1985 – "overlooking minor cheating but punishing large deviations from quotas."[14] It is, after all, the only member with meaningful surplus capacity at all

times – currently 2 million barrels per day.[15] The key conclusion is that while an implicit Saudi threat to penalize non-compliance "substantially reduces the payoff from cheating," it does not eliminate the basic incentive to modestly overproduce.[16] Assuming a 6% annual discount rate, for instance, production to capacity by UAE would yield it a 22.5% revenue increase even if the Saudis retaliate; on the other hand, the Saudi gain from such a move would be only 1.9%, and the Saudis' payoff actually turns negative if they retaliate against three other members.[17] Hence, the kingdom's own vulnerability to a major price decline suggests that its retaliatory threat should not be considered fully credible. This may explain why overproduction during the 1985-96 "tit for tat period" worsened to 7.1% from the 1.6% it was during the prior two years.[18]

As this article and historical observations suggest, Saudi Arabia is not capable of single-handedly monitoring compliance. The most basic reason, then, to explain non-compliance is that it is advantageous to a member's short-term interests while largely lacking associated costs. This is not to say that overproduction is never problematic. Griffin and Xiong rely on a variation of the Hotelling principle, which seeks to explain intertemporal decision-making regarding the output of a scarce natural resource, to describe the costs incurred by OPEC's smaller members when overproducing. First, there is clearly a "finite resource base" as the supply of petroleum is limited, with divergent revenue maximizing strategies (i.e., short-term vs. long-term) leading to "differences in producer's discount rates"; and second, many members lack the technological capacity to produce beyond quota, at least at an economic marginal cost.[19] Iran, for instance, has long pushed for lower quotas (and, as we have seen, demonstrated high compliance) because its oilfields did not permit rapidly rising output.[20] Some have also argued that such members as Iraq, due to political reasons, have not allowed foreign direct investment that would be sufficient to

increase capacity beyond its quota levels.[21] But as above analysis suggests, the vast majority of cartel members have been consistently capable of engaging in quota-breaking since 1982.

Table 3: OPEC Quotas and Reserves, 12/2001		
	Member Quota as % of Total Quota	**Member Quota as % of Reserves**
Algeria	3.194	0.196
Indonesia	5.185	0.704
Iran	14.680	0.103
Kuwait	8.021	0.058
Libya	5.353	0.104
Nigeria	8.237	0.182
Qatar	2.590	0.119
Saudi Arabia	32.503	0.086
UAE	8.728	0.062
Venezuela	11.508	0.103
Source: OPEC		

Historically, OPEC's worst offenders were relatively small, marginal producers, an empirical result confirmed by Claes, and one that is consistent with game theory.[22] Realizing this, the cartel deliberately tries to appease its small members with disproportionately high quotas, when adjusted for their long-term productive power (i.e., crude oil reserves).[23] This is anecdotally shown using December 2001 data in Table 3 above. Saudi Arabia, the member with the largest quota share by far, has the second lowest quota when expressed as a percentage of its reserves. On the other hand, this percentage is the highest for the relatively minor producers of Algeria and Indonesia, both of which are in the bottom half when their production is measured in absolute terms. Hence, while members such as these may have a higher propensity to overproduce, their quotas tend to reflect their frequent demands for higher quotas and thus serve to reduce observed overproduction in Table 2. Also, it is useful to note the fact that OPEC ministerial meetings (conferences which formally approve all quota changes) occur quite frequently – on average, more than twice a year. This means that "the possibility of renegotiating one's quota reduces the short-term implications of these decisions for the countries' oil policies," leading to greater output flexibility and "more cooperative" members.[24]

4. Specific Influences on Overproduction

It is clear that although OPEC policy formally discourages overproduction, the cartel is not organized to stringently enforce its decisions on wayward members. But what are the actual factors that influence the level of quota-breaking, across countries as well as intertemporally for individual countries? In this section, common features of the international oil market and country-specific characteristics will be discussed in a theoretical context; in the next, I turn to regression analysis.

Dahmani and Al-Osaimy model four "oil market fundamentals" – two on the demand side and two on the supply side – as explanatory variables that affect OPEC's overall level of overproduction.[25] They limit the scope of their research to a 1996-2000 time series. The only statistically significant influence on deviation from quotas during the entire period comes from OECD oil stocks. The correlation is strongly negative. When two sub-periods are considered separately, however, OECD demand also becomes significant with positive correlation, which is intuitive since greater demand should logically lead to expanded output by revenue-hungry producers.[26] (Here, demand is defined as total consumption by all OECD members).[27] Arguably the most insightful part of this paper includes the tests of causality, and the authors conclude "that there is unidirectional causality running from OECD oil demand and OPEC oil supply to the [member country] compliance level."[28] The third variable found to causally affect compliance is oil stocks.[29] This conclusion disproves the intuition that greater compliance (i.e., reduced overproduction) hinders growth of stocks; in other words, causality flows the other way.

This analysis certainly yields some important results, particularly because of its nuanced approach – considering both the effect of market forces on overproduction, as well as the possibility of reverse causation. However, the paper suffers from a data set that is too limited to

make meaningful inferences about a quota system that has been in effect for over two decades. Its conclusions are only relevant to the late 1990's, a turbulent time in the oil market and arguably not one that is representative of the entire period since 1982. Furthermore, the authors appear to include April-June 1998 data in their regressions, even though we've seen already that quota-breaking during these months reached unusually high levels. In a 54-month time series, the impact of such outliers could be massive. Finally, the paper neglects all country-specific factors, since it considers only consolidated statistics for OPEC as a whole. This strategy contributes to an overly small data set and also disregards variables with potential explanatory power.

It was mentioned previously that a member's level of overproduction tends to vary inversely with the size of its quota. Because they have less to lose from consequences of non-compliance, "the smaller countries… are less loyal to the agreement."[30] In fact, Ecuador and Gabon, two of OPEC's smallest members, ended their membership in the 1990's after gaining notoriety for overproduction and finally deciding to escape the quota system altogether.[31]

We also saw that differences in revenue discount rates – the conflict between producers who seek long-term price appreciation and those who seek to maximize short-term gain at any cost – may lead to an overproduction policy in the latter group. However, some experts have arrived at counterintuitive conclusions. Claes, for instance, does not find strong substantiation of such a causal relationship.[32] Also, given that OPEC's "periphery" in the Third World tends to be poorer than its "core" of wealthy Gulf states, one might expect such marginal producers as Algeria and Indonesia to pursue "the maximization of revenues now and worrying about the consequences later."[33] And yet, Table 2 demonstrates just the opposite. Akacem and Glahe concur, noting that rising populations and declining oil revenues in Gulf members over the last two decades have lowered income disparities within the organization.[34] Their work suggests that

population level, as well as per capita income, are variables that should be included when modeling overproduction.

Moreover, the estimation of discount rates is, of course, an inherently speculative process and depends on multiple assumptions, which could explain the lack of empirical evidence for its significance. An important related question is whether there are certain observable features of states that follow a short-term revenue maximization strategy, which I will attempt to answer in the next section.

Claes adds that there is anecdotal evidence to indicate that the level of overproduction is affected by a member's military expenses (e.g., Iraq during its conflict with Iran) and the quantity of its state-owned "downstream assets," such as Kuwait's refineries.[35] Some observers mention domestic economic policy as another contributing factor. Barnes, for instance, suggests that Indonesia (normally a high-compliance member) has occasionally relied on production above quota to fund "subsidized sales of petroleum products to the domestic market."[36] Similarly, Venezuela's newly elected President Hugo Chavez made a deliberate decision in 1998 to curb the country's historically "aggressive" level of overproduction.[37] His political commitment apparently had a dramatic effect; overproduction fell from 33.29% in the period January 1996 – June 1998 (excluding outliers) to a mere 1.30% in July 1998 – December 2001.

A related notion is the government's commitment to expanding the domestic petroleum industry – both extraction and refining sectors – through domestic and/or foreign direct investment. It is intuitive that FDI which increases output capacity beyond the quota level may facilitate overproduction. Nigeria, for instance, "has been working to boost its… production capacity" in recent years and is now planning to demand a larger quota; if this were denied, it could resort to quota-breaking.[38] Alhajji goes one step further and uses UAE as a case study to

show that "refinery capacity" also plays a role, particularly for oil-exporting countries that simultaneously rely on imports of refined products for domestic consumption.[39] Though his models exclude some relevant variables, he discovers that "oil and oil-related imports" have a statistically significant correlation with the "competitive behavior" of this chronic quota-breaker.[40] These results should not be extrapolated to OPEC as a whole, since the proportion of refined products in the import mix markedly declined for many of its members (including Saudi Arabia) since the 1970's.[41]

5. Model Specifications

In the present literature, there is a lack of a rigorous statistical analysis of OPEC's level of compliance over the entire 1982-2001 period, with the limited model of Dahmani and Al-Osaimy coming perhaps the closest. The principal difference between my model and theirs is that mine treats each individual country as a separate entity, rather than amalgamating OPEC data. This is intended to allow for the addition of country-specific explanatory variables. However, I build on their work by including several features of the international oil market from their model. Also, the dependent variable in both models (percentage deviation) is identical.

One problem encountered in the course of data collection is the deficiency of publicly available trade and industry statistics for smaller OPEC members, particularly Iraq, Libya, Qatar and UAE. This means that some potentially meaningful explanatory variables, such as the level of FDI and output capacity, are not in the model. Also, most of the available data is annual, which limits inferences about short-term shifts in overproduction and increases the likelihood of autocorrelation. With this in mind, the following are the eight explanatory variables, of which the first three represent market variables and the next five are country-specific.

1. *Price*: U.S. refiner acquisition price of crude oil (constant 2001 dollars per barrel) – used as a proxy for the world market price

2. *Quota*: Total OPEC output quota (thousands of barrels per day)
3. *Stocks*: Total OECD oil stocks (millions of barrels)
4. *Quota Percent*: Member's quota as percentage of total OPEC quota (%)
5. *Population*: Member's population (millions)
6. *GDP*: Member's per capita GDP (thousands of current dollars)
7. *Petroleum Percent*: Member's petroleum exports as percentage of total exports (%)
8. *Debt Percent*: Member's public debt payments as percentage of total exports (%)

A total of three model specifications all assume a linear relationship, include the variables listed above and rely on a two-sided t-test, but each uses a different approach to treat data from the different members. Model 1 is based on panel data, which includes "multiple observations on each individual in the sample."[42] In this case, the individuals are OPEC member states and observations are drawn from each month within the 1982-2001 period.[§] The panel data approach permits only a single intercept and a single set of coefficients for all eleven countries. The principal disadvantage, naturally, is that this simple model does not take into account the possibility of different responses to changes in explanatory variables amongst the members.

To improve on this approach, Model 2 includes a set of dummy variables to differentiate between members. Like Model 1, there is still a uniform set of coefficients; however, each member now has a unique intercept. The "Algeria" variable, for instance, assigns 1 to Algeria and 0 to all others. When running a regression, it is necessary to exclude one of the eleven dummy variables to avoid the problem of perfect multicollinearity. The excluded variable is "Saudi Arabia", so the dummy coefficients in this model represent marginal differences in quota deviation as compared to the base (Saudi) deviation. Finally, Model 3 is a set of eleven separate regressions – one for each member. Since dummy variables would be redundant in this case, they

[§] There are three exceptions. As discussed, the 4/98-6/98 outlier period is excluded, as is Iraq data after 7/90. Also, OPEC did not set individual member quotas during 10/91-1/92 and 10/92-12/92. (Source: OPEC)

are not included. This model allows each regression to have a unique intercept and a unique set of coefficients, therefore fully taking into account country-specific characteristics.

6. Regression Results

An initial attempt at using the ordinary least squares method of regression revealed massive autocorrelation, which was to be expected given the nature of this time series. Durbin-Watson statistics for both Model 1 (DW = 0.217) and Model 2 (DW = 0.238) confirm positive autocorrelation at the 5% level.[43] This means that adjacent errors tend to have the same sign. Therefore, the generalized least squares approach is a better option to ensure accurate results, because unlike OLS it can be used even when errors are correlated.[44] Accordingly, conclusions for all 3 models are based on GLS regressions, with the assumption of first-order autocorrelation, or AR(1). For comparison, the appendix includes results for OLS regressions.

Summary statistics for the two consolidated models are displayed in Table 4. Coefficients in this case show the effect on "average" OPEC overproduction in response to changes in explanatory variables. Fully half of the quantitative variables show significant results in both models. The *Price* variable is strongly negative, implying that overproduction falls by an average of over 0.5% for every dollar rise in oil prices. This seems to indicate that OPEC members may pursue a revenue target, which would lead to better compliance in a high-price environment but intense quota-breaking during a period of low prices. This result is broadly consistent with discussion in Section 2. However, it appears to partly contradict the conclusions of Dahmani and Al-Osaimy, who find a positive correlation between overproduction and the OPEC basket price in 1996-2000 but a negative correlation in 1996-98.[45] The use of a different price index could partly explain the divergent results, but the most likely explanation may be a longer time series in which the four-year data set used by the authors represents only a small subset. This implies

that the relationship between price and overproduction has fluctuated over time.

Also negative are the *Quota* and *Quota Percent* variables. In the case of *Quota Percent*, the magnitude of the coefficient in both models is greater than one. Everything else being equal, this means that a member with a quota share that is 1% larger than another member's share tends to have a level of overproduction that is more than 1% lower. This finding supports our earlier conclusion that small producers (such as Qatar and UAE) have historically engaged in far greater quota-breaking than the cartel's largest members. *Quota*, on the other hand, shows that member overproduction tends to fall when OPEC's total production ceiling is increased, even when such an increase benefits members proportionally. (Dahmani and Al-Osaimy found a positive relationship here, but correlation in their 1996-2000 data set was not statistically significant.[46]) A likely explanation for the negative *Quota* coefficient is that members (except Saudi Arabia) tend to produce at capacity irrespective of their assigned quota. When quotas rise across the board, their actual production stays constant while observed overproduction falls.

Table 4: GLS Regression Statistics (Models 1 and 2)

	Model 1			Model 2		
	Value	**Std. Error**	**P-value**	**Value**	**Std. Error**	**P-value**
Intercept	19.1675	21.9600	0.3828	**143.7371**	25.8977	* < 0.0001
Price	**- 0.5290**	0.1004	* < 0.0001	**- 0.5654**	0.1076	* < 0.0001
Quota	**- 0.0015**	0.0003	* < 0.0001	**- 0.0022**	0.0003	* < 0.0001
Stocks	0.0083	0.0053	0.1152	0.0084	0.0053	0.1131
Quota Percent	**- 1.1975**	0.1682	* < 0.0001	**- 4.4255**	0.3492	* < 0.0001
Population	- 0.0267	0.0366	0.4653	**0.5614**	0.1827	* < 0.0001
GDP	- 0.4115	0.2448	0.0930	0.8442	0.4314	0.0505
Petroleum Percent	**0.2796**	0.0814	* 0.0006	**0.2559**	0.1025	* < 0.0001
Debt Percent	**- 0.1904**	0.0712	* 0.0075	0.0600	0.0801	0.4538
Algeria	N/A	N/A	N/A	**- 128.5859**	15.0292	* < 0.0001
Indonesia	N/A	N/A	N/A	**- 199.0052**	33.8087	* < 0.0001
Iran	N/A	N/A	N/A	**- 78.5128**	12.7260	* < 0.0001
Iraq	N/A	N/A	N/A	**- 85.2250**	12.4162	* < 0.0001
Kuwait	N/A	N/A	N/A	**- 115.9888**	13.0241	* < 0.0001
Libya	N/A	N/A	N/A	**- 112.0866**	12.9326	* < 0.0001
Nigeria	N/A	N/A	N/A	**- 153.6836**	21.2091	* < 0.0001
Qatar	N/A	N/A	N/A	**- 149.1041**	15.1771	* < 0.0001
UAE	N/A	N/A	N/A	**- 95.2594**	13.0245	* < 0.0001
Venezuela	N/A	N/A	N/A	**- 93.4575**	12.3638	* < 0.0001

Note: Values in **bold** are significant at 5% level (based on two-sided t-test)

The only significant and positive variable in both models is *Petroleum Percent*. This variable does not appear to be commonly used in the current literature, but it leads to an important conclusion. It indicates that members with economies that are most heavily dependent on oil revenues for export earnings (primarily Gulf states) tend to overproduce more than countries with a more diversified international trade profile. The regression therefore confirms what is intuitively expected and shown historically in Section 2.

Finally, *Debt Percent* and *Population* are both significant in only one of the models. *Debt Percent* is significant and negative in Model 1, suggesting that a greater level of public spending on debt service is correlated with lower overproduction. This is highly counterintuitive, since a rise in this variable represents an increase in fiscal pressure on the government that could be alleviated by expanding oil exports. In Model 2, in fact, the coefficient of *Debt Percent* is indeed positive. However, because it is not even close to reaching significance in Model 2 (p-value = 0.4538), it would not be prudent to make firm conclusions in regard to this variable.

The *Population* variable is significant and positive only in Model 2. Like *Debt Percent*, this variable can be used to represent financial demands on the government. Of course, population pressures are not typically characterized by the abruptness of a large loan payment, but it is reasonable to surmise that an OPEC member with high population relative to other members might have greater need for revenues to pay for social services, which could be raised by producing above quota. The positive sign of the *Population* coefficient represents indirect evidence for precisely such a dynamic. Yet, this variable is neither positive nor significant in Model 1, so the empirical finding in Model 2 is not definitive.

In Model 2, all dummy variables are significant at the 5% level. This is not a surprising result, since it merely confirms that different members have vastly different base levels of

overproduction when compared to that of Saudi Arabia. If the dummies were *not* significant, it would suggest that Model 2 is not an improvement on Model 1. But because the intercepts for different members are clearly differentiated, that is clearly not the case here.

Table 5: GLS Regression Statistics – Coefficients Only (Model 3)

	Intercept	Price	Quota	Stocks	Quota Percent	Popu-lation	GDP	Petroleum Percent	Debt Percent
Algeria	- 8.008	0.250	**- 0.002**	0.007	**- 15.132**	**2.235**	- 2.667	**0.585**	- 0.067
Indonesia	**148.904**	0.142	**- 0.003**	0.008	**- 9.773**	- 0.200	6.520	**- 0.358**	- 0.185
Iran	**210.936**	0.101	**- 0.004**	0.014	**- 12.286**	0.697	**- 13.109**	- 0.053	0.115
Iraq	153.768	- 0.206	**- 0.005**	0.007	**- 13.544**	- 1.796	11.745	0.579	0.069
Kuwait	251.833	**- 2.857**	**- 0.006**	- 0.004	**- 13.841**	29.603	4.038	- 0.665	0.276
Libya	21.782	0.498	**- 0.003**	0.005	**- 9.147**	5.032	**6.725**	0.229	**- 2.538**
Nigeria	50.739	**- 0.656**	**- 0.003**	- 0.010	**- 8.880**	**0.752**	15.630	0.543	- 0.030
Qatar	116.758	- 0.596	- 0.001	- 0.019	**- 33.523**	42.284	**2.024**	- 0.090	**0.467**
Saudi Arabia	100.886	0.074	**- 0.005**	0.001	**- 2.780**	- 6.054	3.894	1.320	**4.060**
UAE	266.024	**- 0.820**	**- 0.006**	0.010	**- 17.601**	**- 35.109**	1.887	- 0.133	**4.409**
Venezuela	241.118	- 0.053	**- 0.004**	0.002	**- 11.431**	- 4.771	**7.391**	0.114	0.209

Note: Values in **bold** are significant at 5% level (based on two-sided t-test)

Finally, we turn to Model 3, in which a separate regression was used to model each member's overproduction over time. Of the eight variables, two are clearly shown to be dominant in Table 5. Not surprisingly, both are also significant in the prior two models. The only variable that is significant for every single country is *Quota Percent*, and as expected, it is universally negative. The interpretation of this variable's coefficient is not the same as it was in Models 1 and 2. In those models, it showed that differences in quota shares among members are correlated with differences in their respective levels of overproduction. Here, on the other hand, it shows the effect of intertemporal change in a given member's quota share on that member's overproduction. Specifically, each member's level of quota-breaking tends to fall when the member obtains a greater share of the overall production ceiling than it had previously. The fundamental explanation, though, appears to be the same as the one mentioned in the context of Models 1 and 2 – namely, lack of surplus capacity outside Saudi Arabia. This theory is supported by the fact that the Saudi coefficient's magnitude is lower than that of any other member.

Similarly, *Quota* is negative for all members except Qatar. As with *Quota Percent*, this result is fully consistent with results in Models 1 and 2. Each member's overproduction clearly declines during a rise in OPEC's total quota. The single exception of Qatar can be explained by the fact that this country has the highest magnitude *Quota Percent* coefficient (–33.523) of all the members. The elasticity of its overproduction is extremely high in terms of its own quota but low in terms of the overall quota.

All other relationships in Table 5 are not sufficiently strong to allow concrete conclusions. A few observations may be made, however. It seems noteworthy that *Debt Percent* was significant for four of the eleven members, including Saudi Arabia. Of the four, three had positive *Debt Percent* coefficients, and all three are Gulf states that are highly dependent on oil for export earnings. In other words, a rise in the public debt burden may lead to greater overproduction, particular for members that lack a diversified export sector and are unable to easily raise revenue for financing the debt through other means. This result is essentially intuitive. On the other hand, the *GDP* variable seems to lead to a highly counterintuitive conclusion. Though only four of the *GDP* coefficients are significant, nine of the eleven are positive, suggesting that an increase in a member's per capita national income leads to greater overproduction. It could be argued that the reverse should be true – governments that are faced with plunging GDP (perhaps a result of domestic recession or lower world oil price) and resulting economic dislocation may have no other option but ignore quotas and produce to capacity. But the *Price* variable shows no clear trend in Table 5 (unlike in Table 4), so we are left with surmising that causality may flow from overproduction to national income, and not the other way. This would suggest that higher export earnings from overproduction lead to a greater level of per capita GDP.

Finally, I make a note about the role of causation in all three models. This study, unlike that of Dahmani and Al-Osaimy, does not include tests of causality. It merely attempts to establish historically observable relationships between the level of overproduction and the explanatory variables. For this reason, it would be inappropriate to conclude with certainty that these variables directly "cause" changes in overproduction. All that should be said is that there is statistically significant correlation between variables. In some cases, of course, causation (if present) could only flow in one direction. It is unreasonable, for instance, to suppose that overproduction has any effect on a country's population. On the other hand, it is entirely possible that the pressure of a rising population may lead a government to violate quotas, as seems to be the case for Algeria and Nigeria. In most cases, though, reverse causality could certainly occur.

In particular, overproduction (like any increase in output on the margin) should put downward pressure on the world price of crude oil. It is estimated that current price elasticity of oil supply is close to -0.10, so that a 1% increase in supply generally results in a 10% price reduction.[47] However, as Table 1 suggests, a moderate level of overproduction (5% to 7% above quota) has been the norm for OPEC over the last twenty years. This suggests that the market may automatically price in a slightly higher actual supply whenever OPEC announces a new set of quotas. Hence, it is reasonable to assume that only a substantial and long-term rise in systemic overproduction would result in the kind of price pressure that is predicted by elasticity theory.

7. Conclusion

This paper attempted to bridge the gap between theoretical models of cartel behavior and historical observations of OPEC's deviation from quotas. We began by tracing the history of OPEC's quota system and analyzing a series of descriptive statistics which suggest that the

organization in the aggregate modestly improved compliance with quotas in the 1990's over the previous decade. We then observed that relatively small, marginal countries – in particular, the Gulf microstates – tend to engage in more persistent quota-breaking than the cartel's larger members, despite the fact that these states are also offered disproportionately large shares of the overall production ceiling.

Next came a theoretical overview of several common and country-specific influences on overproduction, such as various aspects of the crude oil market (notably price), revenue maximization strategies, domestic economic policies, the level of foreign investment, and production capacity. It was also noted that some of these influences are more relevant for some OPEC members rather than others, confirming the need to differentiate between countries when conducting statistical testing. There are clear inconsistencies and notable flaws in the literature, particularly a lack of comprehensive studies of the entire post-1982 quota period.

Finally, GLS regression analysis using monthly data was used to test the significance of eight variables in terms of their correlation with overproduction. As mentioned, this paper does not purport to establish definitive causal relationships, but some variables were found to be significant at the 5% level. In Models 1 and 2, which aggregate all eleven country data sets, the three explanatory variables that tend to vary inversely with overproduction were oil price, overall quota level and a member's quota as percentage of the total production ceiling. There also appears to be a direct relationship between overproduction and the percentage of a member's total exports that consists of petroleum sales. In Model 3, which included separate regressions for each member, only total quota and quota percentage were found to be significant.

Overall, the study confirms what many have long argued about OPEC – it is a structurally weak, market-dependent organization with many members who generally pursue their own

interests rather than long-term cartel viability or oil-market stability. The fact that quota-breaking seems almost endemic is only one consequence of OPEC's weakness, but it is one with substantial ramifications for the international oil market. As policymakers throughout the West denounce OPEC's production limits, it would be prudent to recognize that these limits have never been an impediment to overproduction. It may in fact be useful to think of the quotas not as an immutable output ceiling, but rather a floor beneath which actual production almost never falls. Future research that includes additional macroeconomic variables or includes tests of causality is certainly warranted. Yet even with the limited findings of this paper, it seems abundantly clear that OPEC members historically have acted in an economically rational way that is fully consistent with cartel theory, advancing their interests and those of consuming countries at the same time.

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Appendix A: Methodology of Calculating Output

Energy Information Administration historical monthly statistics on crude oil output include what is known as lease condensate, a petroleum product that is differentiated from actual crude oil.[48] Lease condensate is not included in OPEC quotas, so overproduction statistics would be biased upward if it were included in calculating monthly deviation from quota. To correct for this factor, annual output data that excludes lease condensate was compared to data that includes it. The ratio of the two numbers was then calculated, which by definition must be equal to or less than 1. (For instance, if lease condensate represents 20% of the total petroleum output, the ratio would be 0.80). Every monthly output value from the EIA data set was then multiplied by the ratio in order to correct for the inclusion of lease condensate. In general, the ratio ranges from 0.90 to 1.00 among OPEC members, but because it fluctuates over time and is different from country to country, each member's ratio was calculated for each year between 1982 and 2001. The implicit assumption here is that the ratio remains constant in the course of a single year.

Appendix B: Sources of Data

1. OPEC, *2001 Annual Statistical Bulletin* (available at http://www.opec.org)

    Provides directly or used to calculate: Deviation (dependent), Quota, Quota Percent, GDP, Population, Petroleum Percent, Debt Percent

2. Energy Information Administration (spreadsheets provided by Mr. James Williams; also available at http://www.eia.doe.gov)

    Provides directly or used to calculate: Deviation (dependent), Price, Stocks

3. OECD (available at http://www.sourceoecd.org)

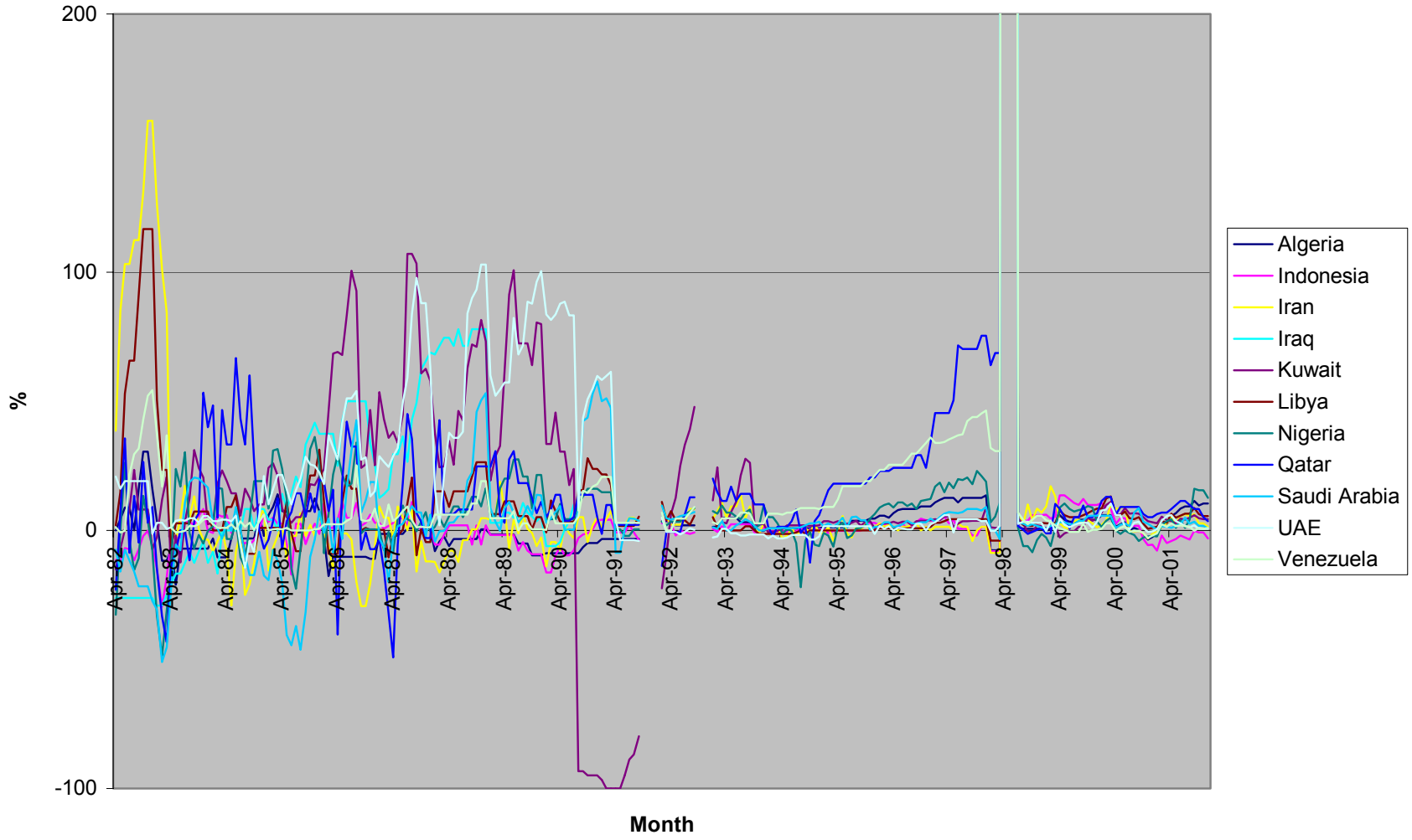
    Provides directly or used to calculate: Debt Percent

Appendix C

Table 6: OLS Regression Statistics (Models 1 and 2)						
	Model 1 (R^2 = 0.09138)			Model 2 (R^2 = 0.2047)		
	Value	**Std. Error**	**P-value**	**Value**	**Std. Error**	**P-value**
Intercept	**40.7075**	12.8106	* 0.0015	**112.9543**	14.9448	* < 0.0001
Price	**- 0.4472**	0.0657	* < 0.0001	**- 0.6805**	0.0754	* < 0.0001
Quota	**- 0.0011**	0.0002	* < 0.0001	**- 0.0012**	0.0002	* < 0.0001
Stocks	- 0.0016	0.0039	0.6909	0.0059	0.0038	0.1253
Quota Percent	**- 0.4023**	0.0598	* < 0.0001	**- 4.3254**	0.2513	* < 0.0001
Population	0.0051	0.0135	0.7041	0.1226	0.0663	0.0645
GDP	**0.5300**	0.1024	* < 0.0001	**1.2514**	0.2247	* < 0.0001
Petroleum Percent	**0.0941**	0.0313	* 0.0027	**0.3585**	0.0609	* < 0.0001
Debt Percent	**- 0.0686**	0.0324	* 0.0346	-0.0106	0.0492	0.8300
Algeria	N/A	N/A	N/A	**- 107.7391**	7.2614	* < 0.0001
Indonesia	N/A	N/A	N/A	**- 99.6281**	11.7319	* < 0.0001
Iran	N/A	N/A	N/A	**- 66.0959**	4.9228	* < 0.0001
Iraq	N/A	N/A	N/A	**- 77.5765**	5.9015	* < 0.0001
Kuwait	N/A	N/A	N/A	**- 101.4681**	6.8955	* < 0.0001
Libya	N/A	N/A	N/A	**- 103.3647**	6.7668	* < 0.0001
Nigeria	N/A	N/A	N/A	**- 100.3808**	7.9047	* < 0.0001
Qatar	N/A	N/A	N/A	**- 124.7063**	8.5254	* < 0.0001
UAE	N/A	N/A	N/A	**- 86.9494**	7.3711	* < 0.0001
Venezuela	N/A	N/A	N/A	**- 77.4685**	5.5875	* < 0.0001
Note: Values in **bold** are significant at 5% level (based on two-sided t-test)						

Table 7: OLS Regression Statistics – Coefficients Only (Model 3)									
	Intercept	**Price**	**Quota**	**Stocks**	**Quota Percent**	**Popu-lation**	**GDP**	**Petroleum Percent**	**Debt Percent**
Algeria	**104.868**	**0.255**	**- 0.003**	- 0.003	**- 19.940**	**1.258**	**- 4.906**	0.173	- 0.047
Indonesia	**182.390**	0.042	**- 0.004**	0.003	**- 11.025**	**- 0.156**	**8.055**	**- 0.366**	**- 0.350**
Iran	**218.208**	0.132	**- 0.003**	0.002	**- 15.301**	**1.438**	**- 7.498**	- 0.025	- 0.088
Iraq	- 102.651	**- 1.705**	**- 0.007**	- 0.021	**- 10.008**	6.607	**58.936**	1.366	0.395
Kuwait	**526.916**	**- 3.342**	**- 0.006**	**- 0.087**	**- 10.558**	**78.927**	**11.428**	**- 2.436**	**- 1.154**
Libya	**90.526**	- 0.207	**- 0.004**	0.011	**- 18.914**	11.175	**8.077**	**- 0.210**	- 0.511
Nigeria	63.927	- 0.369	**- 0.002**	**- 0.021**	**- 11.318**	**0.899**	8.238	0.576	**0.361**
Qatar	**175.347**	**- 0.958**	- 0.001	**- 0.033**	**- 30.902**	27.280	**2.364**	- 0.147	**0.640**
Saudi Arabia	**163.111**	**- 0.821**	- 0.001	- 0.004	**- 1.864**	- 0.752	**2.851**	- 0.634	**- 1.597**
UAE	**181.752**	0.068	- 0.001	**0.024**	**- 19.479**	5.605	**- 5.931**	**0.919**	**- 7.597**
Venezuela	**- 50.939**	0.029	- 0.001	0.002	**- 13.397**	**5.116**	2.560	**0.763**	**0.735**
Note: Values in **bold** are significant at 5% level (based on two-sided t-test)									

OPEC Members: Deviation From Quota



References

[1] House Committee on International Relations, Oil Diplomacy: Facts and Myths Behind Foreign Oil Dependency, 20 June 2002, available from http://wwwa.house.gov/international_relations/107/80291.pdf; Internet; accessed 4 March 2003.

[2] Atmane Dahmani and Mahmoud H. Al-Osaimy, "OPEC oil production and market fundamentals: a causality relationship," *OPEC Review* (December 2001): 319.

[3] Ibid.

[4] Ibid.

[5] OPEC, *2001 Annual Statistical Bulletin* (Vienna: OPEC, 2002): xi.

[6] Harvey Morris, Opec squabbles over falling prices, 19 March 1998, available from http://www.foreignwire.com/opec.html; Internet; accessed 5 March 2003.

[7] Paul Krugman, The Energy Crisis Revisited, 5 June 2000, available from http://web.mit.edu/krugman/www/opec.html; Internet; accessed 5 March 2003.

[8] Dahmani and Al-Osaimy: 317.

[9] OPEC, *Bulletin*: 2.

[10] Jack Hirshleifer and David Hirshleifer, *Price Theory and Its Applications*, 6th edition (Upper Saddle River, NJ; Prentice Hall, 1998): 249.

[11] OPEC, OPEC Statute, 2000, available from http://www.opec.org/Publications/OS/OS.pdf; Internet; accessed 5 March 2003.

[12] Ian Skeet, *OPEC: Twenty-Five Years of Prices and Politics*, (Cambridge, England: Cambridge University Press, 1988): 203.

[13] James Griffin and Weiwen Xiong, "The Incentive to Cheat: An Empirical Analysis of OPEC," *Journal of Law and Economics* (October 1997): 291.

[14] Griffin and Xiong: 306.

[15] John Mitchell et al, *The New Economy of Oil: Impacts on Business, Geopolitics and Society*, (London: Royal Institute of International Affairs, 2001): 57.

[16] Griffin and Xiong: 307.

[17] Ibid.

[18] Griffin and Xiong: 312.

[19] Griffin and Xiong: 313.

[20] Platts Global Energy, Information on OPEC Members, 2002, available from http://www.platts.com/opec/glance.shtml; Internet; accessed 6 March 2003.

[21] Mitchell at al: 56.

[22] Dag Harald Claes, *The Politics of Oil-Producer Cooperation*, (Boulder, CO: Westview Press, 2001): 264.

[23] Griffin and Xiong: 300.

[24] Claes: 148.

[25] Dahmani and Al-Osaimy: 321.

[26] Dahmani and Al-Osaimy: 323.

[27] Energy Information Administration, Glossary, 2002, available from http://www.eia.doe.gov/emeu/ipsr/appc.html; Internet; accessed 22 March 2003.

[28] Dahmani and Al-Osaimy: 327.

[29] Ibid.

[30] Claes: 264.

[31] Claes: 268.

[32] Claes: 262.

[33] Mohammed Akacem and Fred R. Glahe, "OPEC's Road Ahead," *Journal of Energy and Development* (Spring 1999): 221, 220.

[34] Akacem and Glahe: 220.

[35] Claes: 269.

[36] Philip Barnes, *Indonesia: The Political Economy of Energy*, (Oxford, England: Oxford University Press, 1995): 23.

[37] Platts.

[38] Ibid.

[39] A. F. Alhajji, "Why Do Some OPEC Members Cheat?: The Case of the United Arab Emirates," *Journal of Energy and Development* (Autumn 1997): 60.

[40] Alhajji: 66.

[41] Ibid.

[42] Cheng Hsiao, *Analysis of Panel Data*, (Cambridge, England: Cambridge University Press, 1986): 1.

[43] Diana Whistler, The Distribution of the Durbin-Watson Test Statistic, 2001, available from http://shazam.econ.ubc.ca/intro/dwdist.htm; Internet; accessed 22 March 2003.

[44] John Fox, Time-Series Regression and Generalized Least Squares, 2002, available from http://cran.r-project.org/doc/contrib/Fox-Companion/appendix-timeseries-regression.pdf; Internet; accessed 22 March 2003.

[45] Dahmani and Al-Osaimy: 322.

[46] Ibid.

[47] Edward Porter, U.S. Energy Policy, Economic Sanctions and World Oil Supply, 2001, available from http://www.api.org/pasp/sanctionsR.pdf; Internet; accessed 23 March 2003.

[48] EIA, Glossary.