WP 2005-27
December 2005

Working Paper

Department of Applied Economics and Management
Cornell University, Ithaca, New York 14853-7801 USA

An Econometric Evaluation of A Geopolitical Theory of Oil Price Behavior

Ahmad Slaibi, Duane Chapman and Hazem Daouk

Abstract

Previous work on crude oil price modeling has generally focused on two theoretical approaches, either the optimal control analysis of pricing of a depletable resource, or OPEC as a partial monopolist setting oil prices to maximize net present value. Neither has been wholly satisfactory. We consider a different perspective, a game theory based framework in which political and military factors interact with economic considerations for oil exporters and importers to define a target price zone (TPZ). We analyze several issues in this context: monthly vs. annual average prices, beginning and ending dates for TPZs, degree of stability in several price series (WTI, Brent, etc.), FOB and landed prices, real or nominal prices, OPEC behavior, and effect of the Euro exchange rate on dollar denominated oil prices. We conclude that a TPZ system was in operation from 1986 through 2003 and that OPEC acted as a political cartel exercising market power by controlling production in order to seek to maintain prices within the TPZ. The TPZ worked imperfectly but with a substantial degree of predictability for 18 years. In 2004 and 2005 the TPZ system deteriorated for several reasons, and has not yet been re-established.

An Econometric Evaluation of a Geopolitical Theory of Oil Prices

"Perhaps the US government supports the Saudis because it has always believed it had a two-way relation with OPEC generally and the Persian Gulf countries particularly. We give them protection and they supply oil." [1]

"The Bush trip [1986] came as an additional incentive to restore some stability to prices… What they [the Saudis] heard was the Vice President of the United States of America saying that the price collapse was destabilizing and threatened the security of the United States… The Saudis looked to the United States for their own security; surely, they thought in the aftermath of the Bush visit, they would have to be attentive to the security needs of the United States." [2]

Have oil prices been stable in the past? What are the factors that create such stability? We propose that crude oil prices generally stayed within a two-stage sequential price band from 1986 to 2003, an 18-year interval. This target price range system, originally informal, became more structural. It can be described as a Nash equilibrium game theory result. One side, oil importers led by the United States, offered military security in the Persian Gulf in exchange for reasonable stability in prices and secure production. The other side, Persian Gulf producers, have offered stable production

1 M.A. Adelman, March 2005, "Political Economy of OPEC," *Dialogue*, 13(1): page 7. Adelman qualifies this quotation by observing that "OPEC countries owe us nothing".
2 Yergin, Daniel. "*The Prize: The Epic Quest for Oil, Money, & Power*." Simon and Schuster 1992, page 758. This is Yergin's description of then Vice-President Bush's visit to Saudi Arabia in April 1986. In Yergin's view, this explains why Saudi Arabia later that year cut production, subsequently leading to higher prices.

growth and reasonably stable prices in exchange for military security. We believe that OPEC led mainly by Saudi Arabia managed production in an attempt to maintain prices within this price band.

The purpose of our analysis is to evaluate that theory. This is the structure of the paper:

I. Review of the findings of previous research on oil price formation.
II. Description of the Nash equilibrium theory of the target price zone for crude oil prices.
III. Analysis of the target price zone: time span, inflation, Monte Carlo simulation.
IV. Examination of OPEC as a political cartel, how the target price zone worked, and the Euro impact.
V. Conclusion.
VI. Appendix: Evaluating several crude oil price series.

I. Crude Oil Prices: Previous Work

Wirl and Kujundzic (2004), in a succinct summary, suggest that early efforts (1975-1997) to model OPEC's oil prices can be divided into four categories.[3] The first category considers OPEC as the "price setter" maximizing the Net Present Value (NPV) of oil revenues. The second regards OPEC behavior as a price reaction function: the price of oil is directly related to the gap between demand and the production capacity of OPEC countries. A third category of studies includes Ramcharran (2001) who applies target revenue theory to analyze prices and output, and Tang and Hammoudeh (2002) who apply the target zone model to oil prices. The last category of studies includes Chapman and Khanna (2000, 2001) who examine the behavior of OPEC oil prices from a

[3] W-K summarize 33 studies, a helpful resource.

"politico-economic" framework. In their own analysis, Wirl and Kujundzic (2004) investigate the relationship between OPEC Conferences and world oil prices. Their conclusion: while the Conferences have little identifiable impact, the authors believe OPEC itself has significant impact.

In recent work, Kaufmann et. al. (2004) in their article "Does OPEC Matter?", employ econometrics to investigate the relationship between real oil prices and OPEC behavior. The article finds that there is a significant correlation between real oil prices, OPEC capacity utilization, OPEC quotas, the amount of cheating, and OECD stocks. The article also indicates that OPEC affects real oil prices by influencing the variables under study. A similar point is made by Mazraati and Jazayeri (2004), who demonstrated that when the production compliance of OPEC members was between 94% and 99% of their assigned quotas, higher oil prices were achieved.

Several authors have tried to define structural models of world oil prices. Tang and Hammoudeh (2002) conclude that these efforts have been unsuccessful. They explain this failure as a result of the conventional approach taken by these models: they utilize oil consumption and production, population growth, GDP growth, and price elasticity variables in an attempt to explain price variability. These models ignore other important factors such as political, economic, and military variables that seem to have an impact on the behavior of world oil prices. In a similar vein, Smith (2005) asserts that "All traditional explanations of OPEC behavior (i.e., competitive, Cournot, dominant firm, etc.) are strongly rejected." Smith favors a bureaucratic, consensus-making cartel hypothesis.

Barsky and Kilian (2004) examined the sudden and major recovery in prices between March 1999 and November 2000. They argued that this increase, engineered by OPEC, was surprising since there was no military conflict in the Middle East and in prior OPEC meetings since 1986 the cartel have failed to demonstrate such market power. They also argue that oil prices in 2001 started to fall despite turmoil in the Middle East, higher demand, the terrorist attacks of September 11, 2001, and the subsequent invasion of Afghanistan. They conclude that "it is far from obvious" what linkage channels exogenous political events in the Middle East as factors driving global oil prices.

Ahrens and Sharma (1997) examined annual deflated oil price data from 1870 until 1990. They found that the price of oil exhibited a deterministic trend generated by stationary processes. The type of the trend, whether it is stochastic or deterministic, is critical to assess observed variation in prices or stock depletion. A deterministic trend is exhibited when the data generating processes show a trend in a time series that is predictable. If oil prices exhibited a unit root stochastic trend then these prices would have been randomly distributed over time without bound and with variance increasing as the time series proceeds. However, Ahrens and Sharma were able to determine that oil prices don't experience what is known as "unit root" or "random walk"; these prices follow an established time-trend over the 120 year period.

Griffin (1985) examined the oil production of OPEC and non-OPEC countries under four models: cartel, competitive, target revenue, and property rights. Price and production quarterly data of each country from 1971 to 1983 were used to test the above four theories. Griffin concludes that the competitive model could not be rejected; however, a partial market-sharing cartel model dominates all other models. Some of

Griffin's work has been later reexamined by Ramcharran (2001, 2002). Ramcharran (2001) tests the target revenue theory (TRT), which holds that OPEC reduces or increases oil production simultaneously with real price increases or decreases in order to equate revenues with domestic investment needs. Using data from 1973 to 2000 he concludes that the strict version of TRT does not apply. In other words, production is related but not proportionally to domestic investment needs and to pricing changes. Ramcharran (2002) retests the competitive model using data from 1973 to 1997 and obtains a negative and significant price elasticity of supply. He concludes that the competitive model fails to explain OPEC production pattern.

The target price zone has been examined by Hammoudeh (1996), Tang and Hammoudeh (2002), Chapman and Khanna (2000, 2001), and Horn (2004). Hammoudeh (1996) and Tang and Hammoudeh (2002) examine the target price zone (TPZ) model in the context of OPEC prices and policies. Hammoudeh (1996) examines oil price dynamics within a given target zone and the available OPEC policies to readjust or defend the price zone. In the second paper, Tang and Hammoudeh (2002) use oil price monthly data from 1988 to December 1999 to propose that the TPZ was between $15 and $25, and that OPEC maintained this band by controlling production. They postulate that the upper limit of the price band has been set by OPEC to make new exploration and development only marginally profitable and on the other hand the lower limit ensures that the current production is profitable.

Horn (2004) concludes that the short and long-run marginal cost of oil production, even in high cost regions, was far less than the OPEC $22 - $28 price band.[4] In contrast

[4] Chapman and Khanna argue that production cost (including a return on investment and a risk premium) was on the order of $5 per barrel in the Persian Gulf.

with Tang and Hammoudeh (2002), Horn believes that the lower bound was set as a result of the strong position of OPEC as a partial monopolist. OPEC set its own sales strategy, taking into consideration market conditions and the reaction of other producers to its strategy, so as to reach its TPZ. In contrast, the upper bound was set to prevent a change by oil consumers to alternative energy sources or energy saving policies. He uses GDP growth, nominal oil prices and production, and demand and supply elasticities to predict that unless OPEC breaks up, prices would remain in the \$20 - \$30 range until 2020. If the cartel were to have ceased to exist, lower prices were possible. He also states that using today's technology, synthetic oil based on oil sand or coal can be produced at 25\$/bl and 30\$/bl respectively.

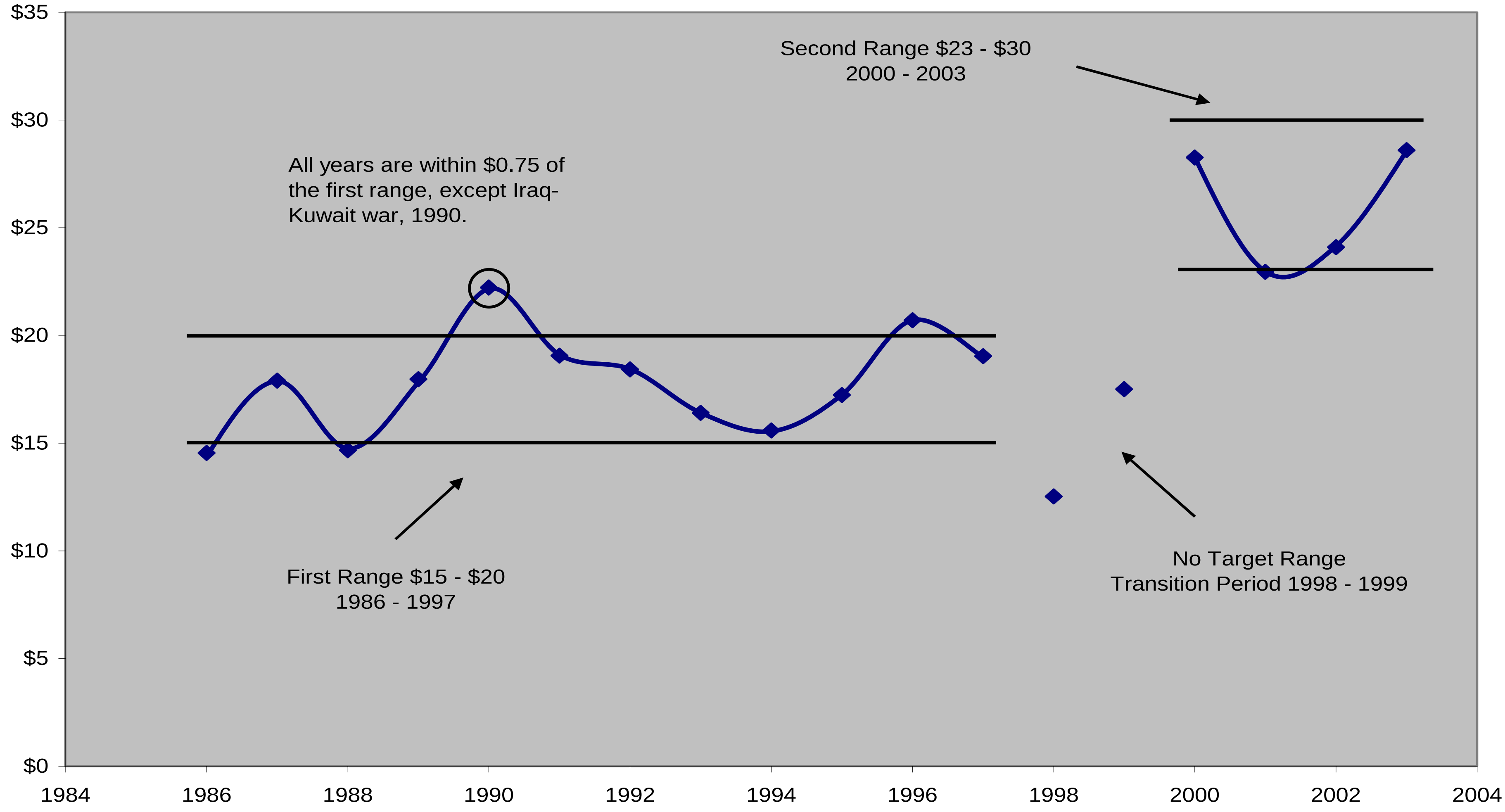
II. A Target Price Zone as Nash Equilibrium

Chapman and Khanna (2000, 2001) proposed the first crude oil price theory that seeks to integrate economic analysis with consideration of both political and military variables. They proposed a target price zone as the result of a Nash Equilibrium within a military security framework intended to provide stability for the Persian Gulf governments.

We also believe that the target price zone was created as the result of that Nash equilibrium. Our proposed TPZ suggests that the global crude oil prices exhibited variations within and around the \$15 - \$20 range from 1986 to 1997 and the \$23 - \$30 range[5] from 2000 to 2003 (Figure 1). The upper and lower bounds of the TPZ were created as the result of a politico-economic agreement between oil importing nations

[5] The price range in the later period is equivalent to the old band adjusted for inflation from 1986 to 2000. Thus the second range was equivalent to the old range multiplied by a correction factor. This correction factor is equivalent to 1.44 if the consumer price index is used and 1.52 if the GDP deflation index is utilized.

Figure 1: Annual Average Global Crude Oil Prices



(OECD led by the United States) and OPEC (led by Saudi Arabia) to stabilize prices in a mutually acceptable framework.

Each side accommodated the goals of the other as they determined their strategies toward pricing, production, and political and military policy. Consider the effect of high oil prices on OECD countries. The total value of oil imports to the US and other importing OECD countries would increase (because the demand of petroleum is generally considered to be price inelastic). High oil prices would also lead to a small reduction in the growth of GNP in most oil importing countries.[6] Such a scenario has in the past led representatives from American states without oil production to call for the end of political and military support to the Persian Gulf regimes. See for example the position taken by congressmen from oil consuming states in the high price period in 2000.[7] In addition, oil prices consistently beyond our proposed zone would make oil production from higher cost fields feasible. At the same time, high oil prices increase the depletion of domestic oil produced in the United States and the North Sea and an increase in investments by OECD companies in oil exploration and development in non-OPEC producers.

Remember that this discussion is historical, focused upon 1986 – 2003 time period. During these years, Persian Gulf producers had a different set of impacts arising from high oil prices: they would have had to contend with a loss of market share as more oil was produced in other parts of the world. In addition, higher oil prices and the subsequent higher economic rent and net profit in Gulf countries could lead not only to Dutch disease, but also increase the potential for regional instability. This instability

---

[6] Jones et al (2004) reviewed 76 recent macro economic studies and concluded that a long run elasticity of GDP with respect to oil price of 0.055 is typical of these studies. Brown (2004) has a similar conclusion.
[7] New York Times 2000, March 2, 19, 23, and 29.

could arise from the lower level of US political and military support[8] to the governments of the Persian Gulf and the greater possible gain to successful regional military activity with the ambition of acquiring increased petroleum wealth. In contrast, with low prices OECD countries enjoyed a higher GNP growth. However, low oil prices encouraged consumption, and reduced domestic production from higher cost fields. Low prices meant less investment in improving energy efficiency and in energy alternatives, and higher dependence on imported oil. In addition, with low prices the oil industry in OECD countries would lose profit due to both lower prices and less domestic oil production. This would encourage the oil industry to pressure the OECD governments to end support to Persian Gulf regimes and their low priced supply.

The Persian Gulf producers also experienced negative effects in periods of low oil prices. Low oil prices meant lower revenues and higher production. OPEC gained market share but this also implies faster depletion of crude resources. Reduced economic rent could create internal economic problems that could destabilize the region and put pressure on exposed local regimes without political and military support from the West.

The end result was a target price zone system from 1986 to 2003 that guaranteed stable and satisfactory returns to oil producing countries and companies without deterring economic growth for oil-consuming countries and businesses. Table 1 summarizes the arguments made to explain the impact of prices outside and within the TPZ. It suggests the motivations leading each side to accept the TPZ.

One mechanism used to try to keep oil prices within the TPZ in the 1986 – 2003 period depended on varying Saudi Arabia and OPEC oil production to interact with growing global crude demand and maintain the TPZ (this point is taken up in greater

[8] Again, please see above New York Times references.

Table 1: Factors affecting decision making within the game theory framework

Price per barrel	Impact on OECD Countries	Impact on Persian Gulf Oil Producers
Low	• higher GNP growth • greatly increased oil consumption • much more imports • more pollution, climate change • less investments in improving energy efficiency and alternatives • shut some domestic production • end Persian Gulf political support by OECD oil industry	• higher market share • lower revenue, greater volume • faster depletion and less economic rent • less stability due to internal economic problems • less investments in new explorations and better extraction technology • loss of political support for Persian Gulf governments from OECD oil industry
Within the target price range	• stable GNP growth • stable OECD oil production • slow growth in oil consumption • slow growth in import share • stable prices • ANWR production feasible • continued support for Persian Gulf governments	• continued OECD political, military support • stable revenue • sufficient economic rent • stable market share • continued investments in exploration and development • cooperation with OECD oil industry
High	• decline in GNP growth • rapid near-term growth in domestic production • stable or declining consumption • higher value of oil imports • ANWR production profitable • OECD Persian Gulf political and military support opposed by oil consumers	• loss of OECD political, military support • increased incentives for other non-OPEC production • increased incentives for cheating within OPEC • less market share • less production, more profit, • high economic oil rent and possible Dutch disease • less stability due to greater payoff to successful control of oil resources

detail later in the paper). None of the major players (OECD and the Persian Gulf) had the incentive to shift from the TPZ, hence creating the pure strategy Nash Equilibrium. Recently, the emergence of China and India as new forces in the demand for crude oil, in addition to other factors[9], have upset this equilibrium. However, it is possible that in the long run a new Nash equilibrium may be reached. This equilibrium would create a new TPZ that, as in the past, would guarantee each player the maximum attainable results given other players' interests.

Historically, we believe oil markets have exhibited several structural shifts creating 5 distinct time periods in the past 6 decades following WWII. These structural shifts were prompted by political, economic, and military factors around the globe. The first period starts with the introduction of the post-WWII competitive price market in 1948 and continues past OPEC's formation in 1960 and into the early 70s (mainly until 1973). During this stage, nominal oil prices were stable and predictable; however, real prices were slowly declining because inflation was reducing the real value of oil.

In the 1973 war, Arab nations attacked Israel on Yom Kippur and soon afterward some Arab oil-producing countries lead by Saudi Arabia cut oil production and enforced an embargo on oil shipments to most Western countries. This reduced supply and led to a price spike creating a new oil price reality that continued into the early 80's. By the end of 1985, excess OPEC supply, reduced demand, and higher market share for non-OPEC producers caused oil prices to collapse.

The third period started in August 1986 with an OPEC agreement, backed by other non-OPEC producers, to cut production and stabilize oil prices. Chapman and

---

[9] These factors include sharp reduction in excess supply capacity in oil producing countries, weakening of the US dollar in 2003 and 2004 prior to recovery in 2005, limited refining capacity, and turmoil in the Persian Gulf and Nigeria.

Khanna (2000), following Yergin (1992), believe that this OPEC agreement was the result of discussions between the Saudi and other Persian Gulf governments and then-Vice President George H. Bush to stabilize oil prices at a higher level. Although oil prices fluctuated in this period, annual averages were more stable and varied mostly between the $15 and $20 range as shown in Figure 1. Adelman (2002) describes oil prices in this period as "more volatile than other commodities" but the fluctuations were of smaller magnitude than in the second period.

The exact date when the third period ended is debatable. Tang and Hammoudeh (2002) consider the years between 1988 and 1999 to be a coherent period. In contrast Bakhtiari (1999), Adelman (2002), and Chapman and Khanna (2000) consider 1986-1997 to be a distinct period in which oil prices were relatively stable. We believe that the third period ended in 1997 and what followed was a two year interlude 1998 – 1999 (period 4) that was characterized by a price collapse due to the economic recession in Asia, the increase in world oil supply by 2.25 million barrels per day (the largest increase since 1988), and the increase in world oil inventories following two unusually warm winters[10]. *The Economist* (March 6, 1999) valued oil at some point in this interval, estimated at real costs, to be generally what it was in period 1 (prior to 1973).

However, in the year 2000 the old system was re-established with a higher TPZ. Oil prices moved again into a calmer framework: monthly and annual averages typically varied between $23 and $30. The four year period 2000 – 2003 is our period five. In 2004, this system seems to have collapsed again. However, further data are needed to examine whether a new period (6) has begun. Table 2 summarizes this discussion.

---

[10] World Oil Market and Oil Price Chronologies: 1970 – 2002. Published by the Department of Energy's Office of the Strategic Petroleum Reserve, Analysis Division.

Table 2. Chronological Summary of World Oil Prices

Period	Years	Comments
1	1948-1972	Nominal oil prices were stable and predictable. Real prices were slowly declining as inflation was reducing the real value of the oil barrel.
2	1973-1985	Very high oil prices with fluctuations of large magnitudes.
3	1986-1997	Prices were volatile, however fluctuations were of small magnitude and monthly and annual averages mostly fell between the $15 - $20 range.
4	1998-1999	Price collapse due to Asian recession and excess supply. In certain month the real term oil prices were similar in value to those in period 1.
5	2000-2003	More stable oil framework. Monthly and annual oil prices varied between $23 and $30.
6	2003 - ?	High oil prices due to higher than expected increase in Asian oil demand, lack of excess capacity, weakening of the US$ in 2003 and 2004, limited refining capacity, and turmoil in the Persian Gulf.

III. Analysis of the TPZ: Time Span, Inflation, Unit Roots, and Monte Carlo Simulation

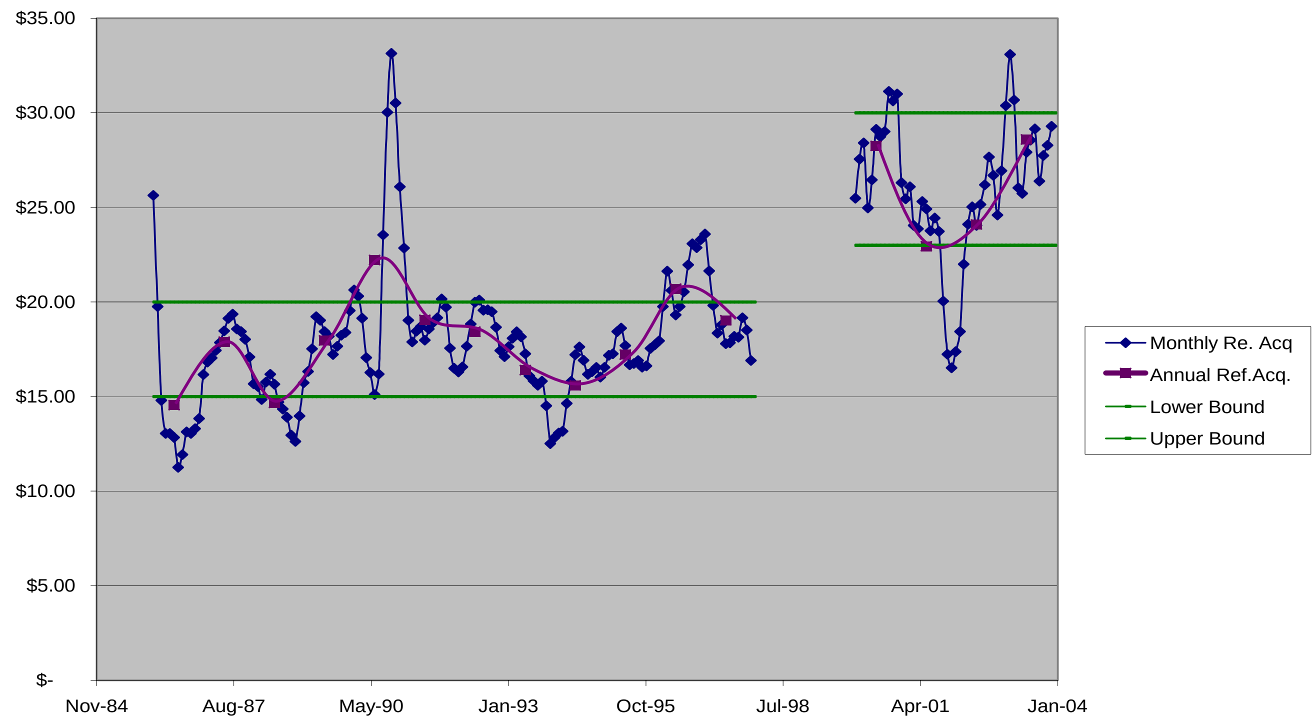
In the following discussion, we examine the target price zone theory and test the goodness-of-fit of the TPZ model. Monthly and annual average US composite refiner acquisition costs in nominal terms were used as the best proxy for global crude oil prices[11] and thus in this paper the two terms are used interchangeably. The monthly and annual averages of oil prices from January 1986 until December 1997 (third time period) and from January 2000 up to September 2003 (fifth time period) are presented in Figure 2. As shown in Figures 1 and 2 the annual average crude prices visually fit our proposed TPZ. In the following sections we statistically analyze monthly and annual averages to evaluate our theory. Although monthly average oil prices over the same period exhibit more variation than do annual averages, we will analyze monthly prices because they provide more data points.

a- Stability, Auto-Regression, and Monte-Carlo Simulation

Almost all the annual averages for the third period (1986 – 1997) fall within or very near the $15 - $20 price band (Figure 2) and in the fifth period the annual averages fall entirely within the proposed $23 - $30 price range. Thus, if we exclude the year 1986 as a transition year, 1988 (increase in Iraq's and Iran's oil production after the end of the Iraq-Iran war), 1990 (Iraq's invasion of Kuwait) and 1996 (operation Desert Strike) as exceptional war-related years, all remaining years have annual averages in the targeted

[11] As explained in the appendix, we show that the data series "composite refiner acquisition cost" in nominal terms seems to be the best proxy for world oil price. It is the weighted average of prices paid for oil booked into US refineries. It includes imported crude from all international sources and domestic crude. This price series covers about 26% of total global crude oil production.

Figure 2: Monthly and Annual Averages of Global Crude Oil Prices



price band. Even if we include these four exceptional years, the average annual deviation from the price band is only 30 cents. In other words, only in exceptionally abnormal years (mainly related to war in the Persian Gulf) does the average annual oil price fall outside the price range and even then its average deviation is $0.3.

$$D = \frac{\left[\sum_{i=1}^{n} \left(Li \left(\left| 15 - Pi \right| \right) + Ui \left(\left| Pi - 20 \right| \right) \right) \right]}{n} \qquad (1)$$

Equation (1) calculates the average deviation of annual oil prices from the price range. The sum of deviations from the years that exhibited annual average price above or below the range are summed and divided by the total number of years covered by the TPZ. In equation (1), D is the average deviation and as noted is equal to 30 cents per barrel, Pi is the average annual price of oil, Li and Ui are dummy variables, Li is equal to 1 if Pi is below \$15 and 0 otherwise, Ui is equal to 1 if Pi is above \$20 and 0 otherwise, and n is the number of years under study.

When considering monthly data, prices are more volatile and the variation is greater than on an annual basis; however, again the average monthly deviation from the price band for the third period has been calculated to be only 75.63 cents. Interestingly the monthly deviation from the fifth time period is 69.35 cents (a difference of only 6 cents).

Less than thirty percent of the monthly averages in periods 3 and 5 fall beyond our proposed price range. However, this proportion decreased to around 15% when 1986 (transition year) and the Middle East war-affected months were ignored. This proportion decreased even more, to less than 10% when the range was increased by 50 cents from each side.

In order to test our proposed time span and to calculate the probability of obtaining a point outside the price band, a time series model is fitted to the crude oil prices series. We ran autoregressions AR(1) through AR(4) and we found the beta coefficient of P(t-4) to be insignificant. Thus, we used AR(3) (third order autoregression) as the best model[12] (equation (2)) to estimate the beta coefficient, the mean, and the standard error of the residuals.

[12] All the coefficients are significant and the model has the highest R squared.

$$P(t) = \beta_0 + \beta_1 P(t-1) + \beta_2 P(t-2) + \beta_3 P(t-3) + \varepsilon(t), \quad (2)$$

where P is the monthly average nominal price ($/barrel) of global crude oil prices; β_0 is the intercept; β_i are the slope coefficients; and ε is an error term.

The results of the auto-regression and the Monte-Carlo simulation provide partial support to our theory. The beta vector (β) was found to be (2.17, 1.55, -0.88, 0.21). The sum of the coefficients on the three lagged terms (1.55, -0.88, 0.21) is 0.88. This implies that the AR model for the price of oil is stationary. The model is therefore $P(t) = \$2.17 + 1.55\,P(t-1) - 0.88\,P(t-2) + 0.21\,P(t-3) + \varepsilon(t)$.

This model was used to run a Monte-Carlo simulation to predict the probability of obtaining future annual average oil prices beyond the proposed range (i.e. at least 1 cent above or below the range). The simulation was run with 50,000 replications representing 50,000 monthly data points; the results are presented in Table 3.

Table 3: Comparing the proportion of the data beyond our TPZ under different scenarios

	Actual	**Monte Carlo Simulation**
All Data.	30%	42%
Data without transition year and war-affected months.	15%	20%
Data without transition year and war-affected months. TPZ extended by $0.5 from each side.	10%	12%

The Monte Carlo values show results around an autoregressive deterministic trend. The results of the actual values are similar but lower suggesting that these actual events are more likely to be within or near the TPZ than would be expected by a Monte Carlo simulation of random prediction around an autoregressive trend of the same actual values. In other words, our belief that the TPZ was a better representation of oil prices than a regression line is partially supported by the Monte Carlo simulation.

b- Chow Test and Time Spans

The next analysis tests for structural change in a regression model that involves data from the three time periods under study. The Chow test is used to examine the effect of structural change due to price or policy alteration on a regression model involving time series data.[13] The idea is to statistically confirm the validity of our proposed time spans. The Chow test uses the residual sum of squares (RSS) as a measure to compare the regressions in the two time periods with the pooled regression. The auto-regressions[14] run were:

Time period 1974 – 1985: $$P(t) = \beta^1{}_0 + \beta^1{}_1 P(t-1) + \beta^1{}_2 P(t-2) + \beta^1{}_3 P(t-3) + \varepsilon_1(t) \quad (3)$$

Time period 1986 – 1997: $$P(t) = \beta^2{}_0 + \beta^2{}_1 P(t-1) + \beta^2{}_2 P(t-2) + \beta^2{}_3 P(t-3) + \varepsilon_2(t) \quad (4)$$

Time period 1974 – 1997: $$P(t) = \beta^{12}{}_0 + \beta^{12}{}_1 P(t-1) + \beta^{12}{}_2 P(t-2) + \beta^{12}{}_3 P(t-3) + \varepsilon_3(t) \quad (5)$$

The time period in equation (5) is comprised of the pooled data of the two time periods in equations (3) and (4). P is the monthly average nominal price ($/barrel) of

[13] Damodar N. Gujarati, "*Basic Econometrics*", McGraw-Hill/Irwin. Fourth edition, 2003. Page 275.
[14] The following analysis was also examined under 0, 1, and 2 lag periods, with the same conclusions.

global crude oil price, β^1_0, β^2_0, and β^{12}_0, are the intercepts, β^1_i are the beta coefficients in period 2, β^2_i are the beta coefficient in period 2, and β^{12}_i are the beta coefficients in the pooled unrestricted model. Finally ε_1, ε_2, and ε_{12} are residual terms in each period. The residual sum of squares of equations (3) and (4) (called RSS_1 and RSS_2) were added to obtain the unrestricted residual sum of squares (RSS_{ur}), that is:

$$RSS_{ur} = RSS1 + RSS2 \qquad (6)$$

with degrees of freedom = df = $(n_1 + n_2 – 2k)$

where n_1 is the number of monthly averages in the second time period, n_2 is the number of monthly averages in the third time period, and k is the number of parameters estimated, 4 in our case (the intercept and the three variables).

The RSS_{ur} is then compared to the residual sum of squares of equation (5) called RSS_r. The idea behind the Chow test is that if in fact there is no structural change then the RSS_{ur} and RSS_r should not be statistically different.[15] Then we compute the calculated F ratio (F_{cal}) in equation (7) and compare it to the tabulated F distribution with k and $(n_1 + n_2 – 2k)$ df in the numerator and denominator, respectively;

$$F_{cal} = [(RSS_r – RSS_{ur})/ k]/ [(RSS_{ur})/ (n_1 + n_2 – 2k)] \qquad (7)$$

In our case, F_{cal} was found to be 17.6. From the F tables, we find that for 4 and 280 df the 1 percent critical value is only 3.32. Therefore, the Chow test seems to support the theory that oil prices 1974 – 1997 has undergone a structural change in 1986, and thus should be considered as two separate periods.

[15] Damodar N. Gujarati, *"Basic Econometrics"*, McGraw-Hill/Irwin. Fourth edition, 2003. Page: 276

The above Chow analysis was repeated using a different data set. This time the oil prices of period five were deflated[16] and added to the data set 1986 – 1997. The idea is to test whether oil prices in period three are structurally different from those in the fifth period. The calculated F value was found to be 3.28; whereas the tabulated F for 4 and 184 df (1 percent critical value) is 3.41. Thus, the Chow test does not support the idea that the two periods were different. Hence, the test cannot significantly detect any statistical difference between the two time periods.

To further test this, we pooled all the data from (1974 – 1997) + (2000 – 2003) and tested whether the new pooled data can be structurally divided into two sets: the first from 1974 to 1985 and the second is the (1986 – 1997) + (2000 - 2003) years. The calculated F value was found to be 17.38; where as the tabulated F for 4 and 328 df is only 3.32 for 1 percent critical value. Thus, the Chow test supports the theory that the oil prices from 1974 until 2003 (excluding 1998 – 1999) can be divided into two sub-periods first from 1974 to 1985 and the second is the (1986 – 1997) + (2000 - 2003) years.[17]

When the Chow test was run on the Hammoudeh theory, the results were different. Hammoudeh proposed that starting in 1988 oil prices followed a new pricing framework, which is the $15 - $25 targeted price band. However, the Chow test does not clearly support the theory that prices from 1980 to 1999 experienced a structural difference in 1988. The F test was only 3.09 when the needed critical value was 3.32 for 1 percent. Thus the statistical test cannot detect any significant differences between the

[16] A correction factor of 1.52 was used to deflate 2000 nominal US refiner acquisition cost prices to the 1986 same nominal price series. See also footnote 5.

[17] The residuals from all the above auto-regressions were plotted against lagged residuals to test for any autocorrelation problems. The scatter plot of the auto-regression equations was always a random cloud which supports the notion that we have no autocorrelation problem in our analysis, and therefore there is no need to correct for it.

two periods before and after 1988.

The interpretation of these results is complex. Recall that we found that using regression equations to model prices has less predictive ability than the TPZ model. Then we used autoregression equations with the Chow test to evaluate our TPZ time periods and Hammoudeh periods. Recognizing this problem, we attempt to test for structural change in our monthly average prices not by regression equations but by comparing the sum of squares above and below our proposed price band. In doing this, we are assuming that the deviations from the price band are approximately normally distributed. We examined the deviations from our data and found our assumption is not unreasonable.

The sum of the squared deviations (RSS_1) from the $15 - $20 range is calculated in periods 3 and 5 (Figures 3 and 4). Then the sum of the squared deviations (RSS_2) from our proposed two-part TPZ (i.e. the $15 - $20 range in period 3 and the $23 - $30 range in period 5) is calculated. A modified version of the Chow test is applied to test if our TPZ is a better model to represent oil prices.

$$F_{cal} = [(RSS_1 - RSS_2) / k] / [(RSS_2) / (n - 2k)] \quad (8)$$

where k is the number of parameters under study (one in our case), and n is the number of monthly averages in the periods being examined. The F_{cal} is 389, which is higher than the required F_{tab} for 1 percent critical value. This is no surprise since the sum of squared deviations in period 5, assuming the $15 - $20 range, is 1430% more than the sum of squared deviations in the same period, assuming the $23 - $30 range instead. Thus, the

Figure 3: Chow Band Old Range

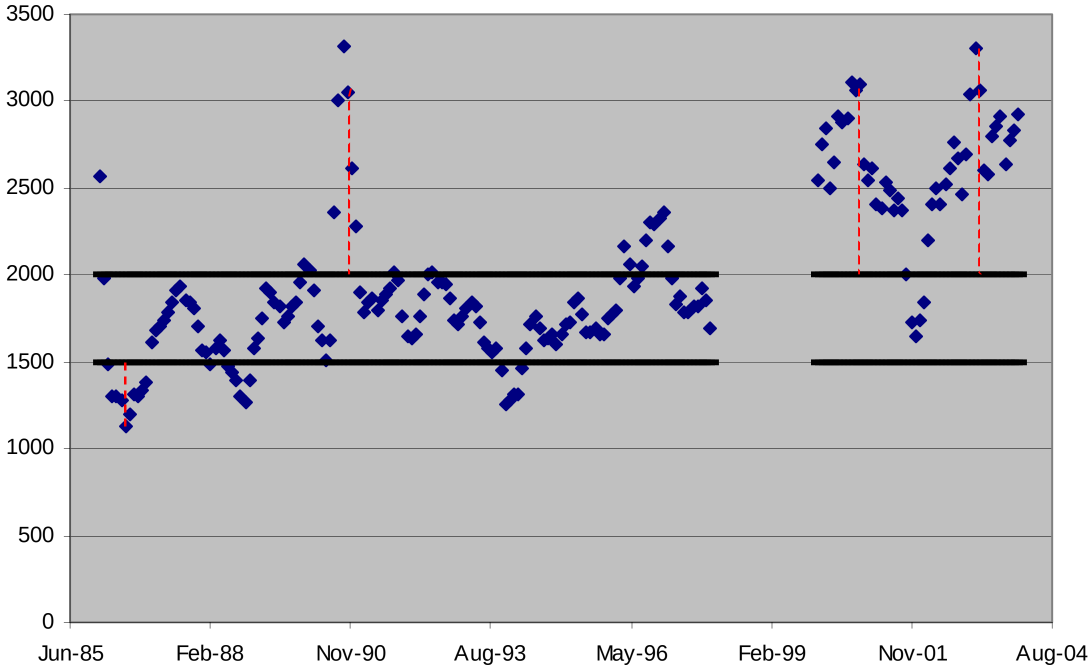
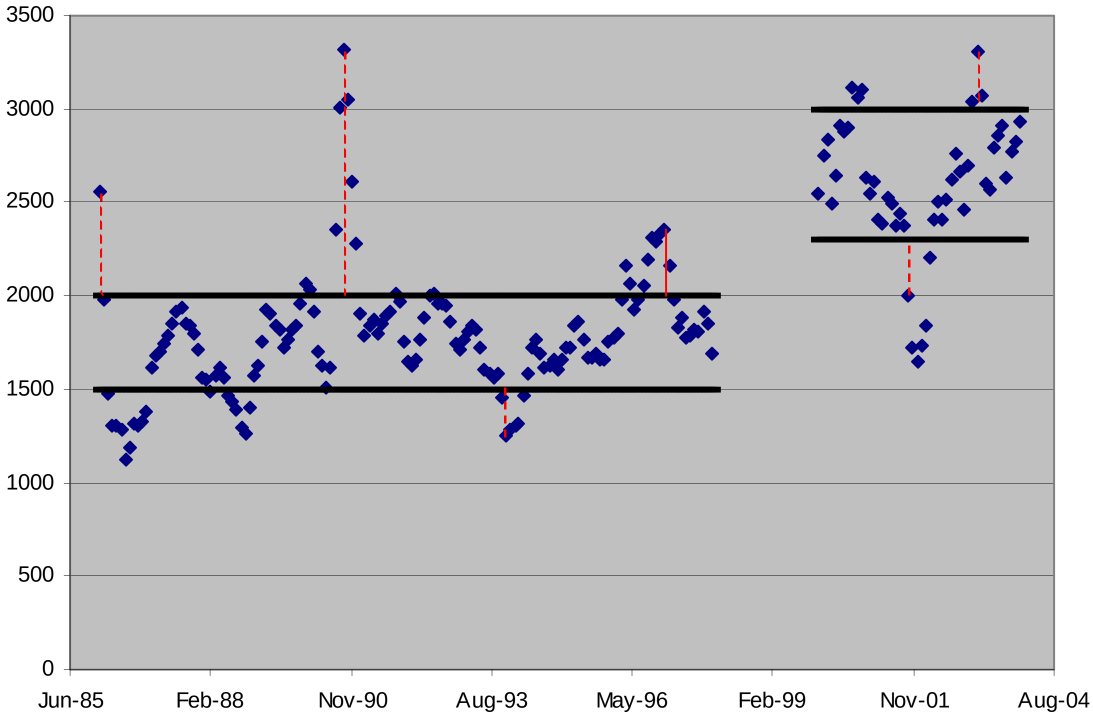


Figure 4: Chow Band Proposed Range



modified Chow test seems to support an interpretation that in 2000 a structural change in crude prices occurred and that the $23 - $30 range is more appropriate for period 5.

Perhaps we can summarize the results to this point in a tentative way: the TPZ theory is not rejected, and seems to have good predictive power; our time periods for the TPZ (1986 – 1997, 2000 – 2003) seem appropriate; and nominal prices give better results than real prices.

IV. OPEC as a Political Cartel, How the TPZ Works, and the Euro Impact

Griffin (1985) tests several theories that attempt to explain world crude oil price variation. He found that although the hypothesis that OPEC acts as another player in a competitive market could not be rejected, there is stronger support that OPEC functions as partial market-sharing cartel. The two equations he specified for the competitive and the cartel models are presented in equations (9) and (10).

$$Ln\,(Q_{it}) = \alpha_i + \gamma_i\,Ln\,(P_t) + \beta_i\,Ln\,Q^{oo}{}_{it} + \varepsilon_{it} \qquad (9)$$

$$Ln\,(Q_{it}) = \alpha_i + \gamma_i\,Ln\,(P_t) + \varepsilon_{it} \qquad (10)$$

where Q_{it} is the quantity produced by any OPEC country (i) in time period t, α_i is the constant, γ_i is price elasticity of supply, P_t is oil price in time period t, β_i is the market sharing coefficient, $Q^{oo}{}_{it}$ is the quantity supplied by the remaining 10 OPEC members in time period t, and finally ε_{it} is a residual term. If β_i is equal to 1 then there is constant market sharing; thus confirming OPEC as a strong cartel. If β_i is positive but different from 1, either higher or lower, this supports a partial market sharing model suggesting a looser cartel. In equation (10) if γ_i is positive this indicates a positive supply slope and hence suggesting a competitive model.

a- OPEC as a Political Cartel and How the TPZ Works

In the above equations Griffin examines the theory of an economic cartel. An economic cartel is defined as an organization of producers collaborating in order to maximize profit. In contrast to Griffin, we believe that OPEC previously functioned as a political cartel with the objective to keep prices stable and oil revenues reasonable and consistent. We used the above two equations while taking into consideration the political and economic conditions that created the TPZ, and we tested equations (9) and (10) inside, below, and above the TPZ. The data used are oil prices and total oil produced by OPEC and by each of its members in periods 1986 – 1997 and 2000 – 2003.

Although we believe that equation (9) dominates other models with respect to its ability to explain production and hence prices, we also ran equation (10) in an attempt to isolate the effect of prices on the quantity produced by an OPEC country. Thus, we first examined the political cartel theory and then the competitive model within the TPZ framework and the results are presented in Tables 4 and 5 respectively.

The results from Tables 4 and 5 allowed us to compare the coefficient of price elasticity of supply and the market-sharing coefficient of each country when world oil prices were inside, above, and below the TPZ. In Table 4, for country i, the nearer β_i is to 1 (i.e. the smaller $|\beta_i - 1|$) the better market sharing is among OPEC members. Hence, $|\beta_i - 1|$ was compared when prices were inside, above and below the TPZ and then the different zones were compared to examine where each model works best. For example in Table 4, when we compare $|\beta_i - 1|$ below versus above the zone, we find that for 9 out of the 11 countries $|\beta_i - 1|$ are smaller below than above the TPZ. This evidence suggests

Table 4: Coefficients of elasticity of supply (Gamma) and market sharing (Beta) assuming the cartel model when no price zone is considered and when oil prices where inside, below, and above the TPZ.

	No Zone			Inside Zone			Below Zone			Above Zone		
	Beta Quantity	Gamma Price	R squared	Beta Quantity	Gamma Price	R squared	Beta Quantity	Gamma Price	R squared	Beta Quantity	Gamma Price	R squared
Algeria	0.47	0.19	0.74	0.57	0.26	0.59	0.55	0.19	0.93	0.4	0.13	0.56
Indonesia	0.15	-0.17	0.14	0.01	-0.11	0.01	0.13	-0.3	0.45	-0.12	-0.18	0.18
Iran	1.21	0.03	0.75	1.14	-0.11	0.77	1.55	0.05	0.8	0.77	-0.03	0.71
Iraq	-2.65	1.18	0.27	-2.21	0.88	0.2	-2.08	2.41	0.48	-0.2	1.57	0.12
Kuwait	1.34	-0.72	0.07	0.69	-0.37	0.04	1.08	-0.37	0.8	5.73	-2.61	0.24
Libya	0.71	-0.02	0.63	0.75	-0.02	0.66	0.78	-0.22	0.86	0.14	0.04	0.11
Nigeria	0.99	0.03	0.83	1.05	0.12	0.88	0.95	0.15	0.75	0.79	0.1	0.72
Qatar	1.41	0.53	0.80	1.88	0.53	0.68	1.31	0.76	0.8	1.57	0.67	0.82
Saudi Arabia	1.18	0.11	0.45	1.31	0.31	0.4	1.65	-0.49	0.8	0.64	0.2	0.3
UAE	1.14	0.00	0.70	1.03	0.4	0.68	1.48	-0.32	0.88	0.81	-0.05	0.47
Venezuela	1.18	-0.09	0.47	1.24	-0.09	0.63	0.97	0.19	0.9	0.65	-0.6	0.11

Table 5: Coefficients of elasticity of supply (Gamma) assuming the competitive model when no price zone is considered and when oil prices where inside, below, and above the TPZ.

	No Zone		Inside Zone		Below Zone		Above Zone	
	Gamma Price	R squared	Gamma Price	R squared	Gamma Price	R squared	Gamma Price	R squared
Algeria	0.35	0.48	0.5	0.1	0.49	0.43	0.2	0.18
Indonesia	-0.12	0.09	-0.1	0.01	-0.22	0.33	-0.2	0.15
Iran	0.43	0.24	0.39	0.03	0.83	0.22	0.11	0.03
Iraq	0.24	0.01	-0.29	0	1.38	0.13	1.55	0.12
Kuwait	-0.25	0.01	-0.04	0	0.24	0.04	-1.45	0.04
Libya	0.23	0.16	0.32	0.03	0.22	0.07	0.07	0.04
Nigeria	0.36	0.27	0.57	0.07	0.67	0.27	0.23	0.1
Qatar	0.99	0.51	1.31	0.08	1.45	0.47	0.91	0.34
Saudi Arabia	0.46	0.18	0.74	0.04	0.46	0.09	0.28	0.08
UAE	0.38	0.20	0.81	0.1	0.49	0.1	0.1	0.01
Venezuela	0.30	0.09	0.45	0.02	0.7	0.34	-0.46	0.06

that there is better market sharing among the OPEC members (i.e. a stronger cartel) when oil prices are below our zone than above it. The same analysis was applied to the price elasticity of supply in Table 5. Table 6 summarizes the results and shows the number of countries with smaller differences ($|\beta - 1|$ or $|\gamma - 1|$) in the respective price zones and under the cartel and the competitive models.

The results show that data after 1985 provide support for the Griffin conclusion that OPEC acted as a partial market-sharing cartel. There is some evidence to support the view that this partial cartel was politically driven and hence seemed to be stronger below the zone than inside it and weakest above the zone. When we tested the competitive model we found that there is also support for this theory; quantities supplied by any OPEC country were more price responsive when prices were inside the zone rather than outside it. It may be the case that rules of supply and demand worked best inside our zone than outside it.[18] However, and more importantly, the R squared values for the competitive model in Table 5 were much less than the partial cartel results in Table 4, supporting our claim that the political cartel model has been a more realistic representation of OPEC production.

Table 6. Number of countries with smaller $|\text{coefficient} - 1|$ in the different price zones and under the cartel and competitive models

Price Zones	Cartel (β coefficient)		Competitive (γ coefficient)	
Inside TPZ vs. Below TPZ	4	7	6	5
Inside TPZ vs. Above TPZ	9	2	9	2
Below TPZ vs. Above TPZ	7	4	9	2

[18] The competitive model works best inside our zone, then below it and least above it.

The above analysis shows that OPEC may have functioned as a political cartel that allowed freer market rules to work when prices were within the TPZ, and utilized market power to push prices back into the TPZ when these prices were outside. However, this theory is limited by the fact that when prices were beyond our range both the cartel and the competitive models were weakly supported. This is due to a limitation in the two models caused by the fact that when prices were high, most OPEC countries were producing at capacity and thus the models were correctly not detecting any change in quantity supplied as a result of a change in price or Q^{oo}_{it}. However, when we observed the relation between monthly global crude oil prices and oil production in Saudi Arabia[19] and OPEC we noticed that when the average price of oil in a certain month went beyond the upper limit of our range, Saudi Arabia (6 out of the 9 times) increased average monthly production in the following month, once Saudi Arabia did not change production, and in the two occasions when it cut production OPEC as a whole increased its average production. If the average monthly oil price went below our lower limit, in some occasions initially Saudi Arabia increased production; however, four out of the five times when average oil prices went below our range they only went back into the TPZ when OPEC cut production.

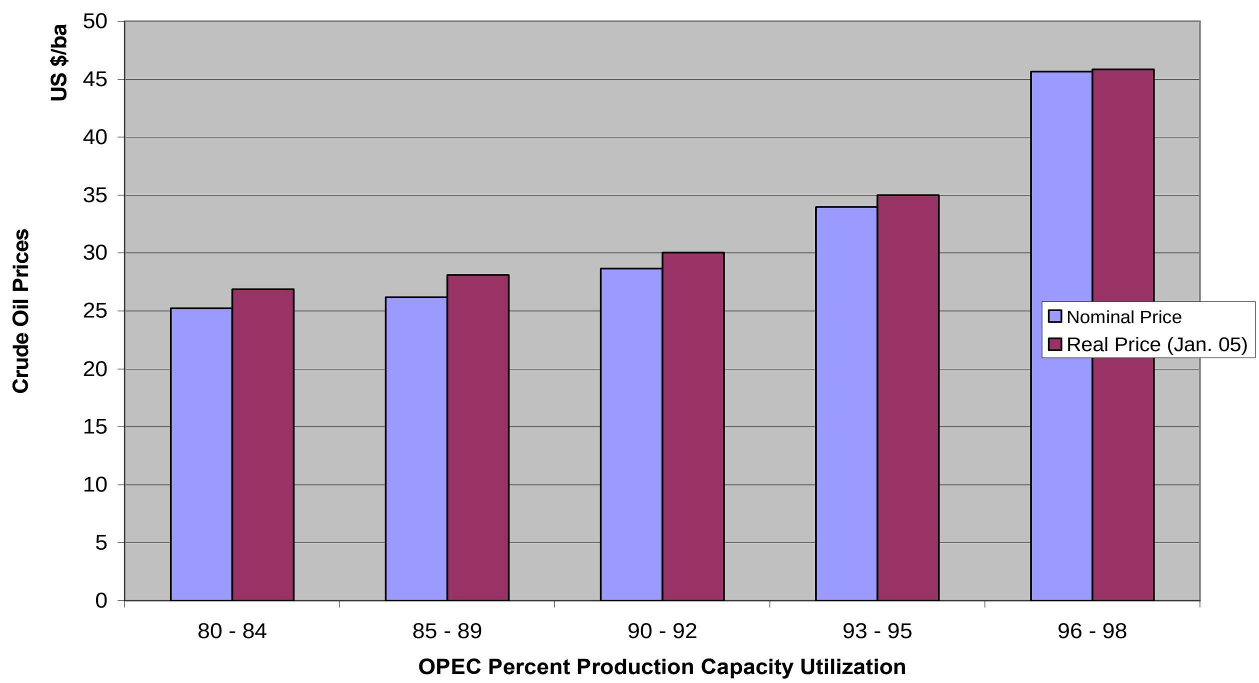
The above-mentioned limitation to our political cartel model (i.e. when prices are above the zone) could possibly explain the record oil prices in 2004 and 2005. When OPEC production approaches its capacity, OPEC can no longer prevent prices from going beyond the zone. The above statement is supported by the fact that, during our period of study, when prices went beyond the zone, OPEC production capacity averaged almost 90%. Production capacity utilization inside our zone averaged around 85%, and

[19] Saudi Arabia almost always had excess capacity.

below our zone it averaged around 78%.

Prices in 2005 were well above the target price zone; this could be caused by the lack of excess utilizable production capacity. In the last few years OPEC excess production capacity has steadily decreased causing OPEC to lose control of the market and hence leading to higher oil prices. As shown in Figure 5, in the last few years as the OPEC production capacity utilization increased from 80% to 92%, oil prices increased around 3$ (12% increase); however as OPEC capacity utilization increases from 93% to 98%,[20] prices increased more than 15$.

Figure 5: Relation between OPEC Production Capacity Utlization and World Crude Oil Prices in Nominal and Real Terms from Jan 2000 to May 2005



[20] When OPEC production capitalization reaches 98% the remaining 2% are usually sour crude in Saudi Arabia. This sour crude is high in Sulphur and needs special refinery to process it.

We believe that as OPEC production capacity utilization moves closer to 100%, prices are going to increase sharply. The future of global crude oil prices will be a function of equation (13):

$$\rho = \frac{\text{(Global Oil Demand – non-OPEC Production)}}{\text{OPEC Production Capacity}} \qquad (13)$$

As ρ approaches one, oil prices will increase at an increasing rate until either global oil demand eases, new non-OPEC production comes on line, or new OPEC production capacity is added.

In summary, the above results support our theory that OPEC acted as a partial political cartel allowing prices to float within our target price zone. However when prices were below our range, OPEC cut production to force prices up. If prices went beyond our upper range, OPEC countries with excess capacity increased production to bring prices back into the zone. Since the TPZ framework dissolved in 2003, higher world oil prices may be expected when OPEC's excess production capacity approaches zero.

b- Examining the Impact of the Introduction of the Euro

Another factor that may be gaining importance in oil price variability is the creation of the Euro. Barsky and Kilian (2004) state that the exchange rate of the US dollar to other currencies will be an important factor in OPEC's decision making. The winter 2004 OPEC meeting included a discussion of the then weakening purchasing power of the dollar.[21] Earlier the Saudi oil minister observed that OPEC wanted higher prices because the purchasing power of the dollar was weak, and at the same time the Venezuelan President asserted that the OPEC price range should be increased due to the dollar's erosion.[22]

The world's largest oil consumers are the United States and China (which surpassed Japan in 2003). The Chinese currency remains pegged to the US dollar. Thus OPEC had in 2003 and 2004 its largest customers paying in the weakening dollar while OPEC members import mainly from Europe and Japan and the Euro and Yen were becoming more costly. Table 7 shows that, with the exception of Venezuela, the remaining 10 OPEC members import more from countries with non-dollar pegged currencies.

Table 7: OPEC countries major import partners[23]

Country	EU (%)	Japan (%)	US (%)	UK (%)	China (%)	Dollar and Dollar Pegged Imports (%)	Non-Dollar Pegged Imports (%)
Qatar	32.5	10.1	8.5	na	na	8.5	42.6
Saudi Arabia	16.6	8.8	11.2	4.9	na	11.2	30.3
Algeria	53.5	na	8.3	na	na	8.3	53.5
Venezuela	na	na	27.5	na	na	27.5	na
Iran	27.8	4.1	na	na	7.6	7.6	31.9
Iraq	22.8	5.6	na	na	8.4	8.4	28.4
Indonesia	na	14.1	8.5	5.4	7.8	16.3	19.5
UAE	12.1	6.6	8.1	5.4	7.8	15.9	24.1
Libya	41.1	6.4	0	6.6	na	0	54.1
Kuwait	20.3	11.1	13.1	6	na	13.1	37.4
Nigeria	25.4	na	9.4	9.6	9.3	18.7	35

21 *New York Times*, Feb. 4, 2004.
22 *The Wall Street Journal*, Dec. 4, 2003.
23 The data source for Table 7 is the CIA World Fact Book 2004. The numbers are percentages of each country's total import. EU numbers include only the major partners. The number would be larger if all the EU countries are included.

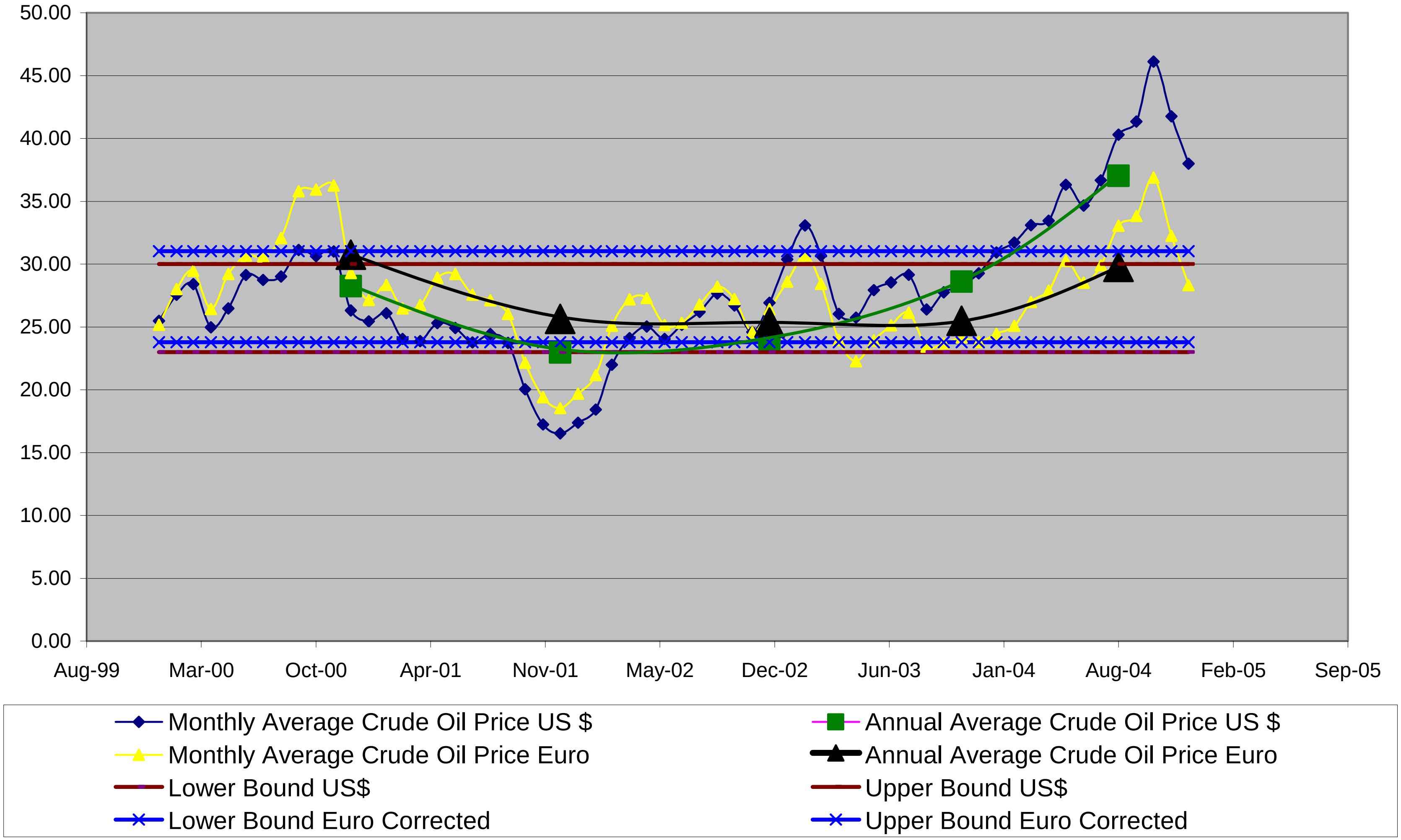
We examined the price of several crude series to see whether in the last few years oil prices have been more stable under Euro pricing or US $ pricing. When the 2000 – 2003 oil prices of each series where changed to Euros and then tested, standard deviations were slightly lower for all series (Table 8). This shows that in the 2000 – 2003 period, Euro pricing of crude was more stable than US dollar prices.

We also compared global crude oil prices using the US dollar and the Euro pricing schemes. This is illustrated in Figure 6. The average annual price of global crude oil in Euros was essentially constant in the three years (2001 – 2003), valued at almost €25.5. However, as we know in 2005 the US dollar halted its decline against the Euro and yet crude oil prices continued to increase. We believe that the introduction of the Euro currency has added another factor in modeling global oil prices and this factor might be of greater importance when the US dollar is weak.

Table 8: Comparing the Annual Variations of Some Oil Crude Prices in US$ and Euro

Annual Averages	2000-2003 Range €23-€30 St. Dev	2000-2003 Range $23-$30 St. Dev
Domestic Refiner Acq Crude cost	2.55	2.87
Imported Refiner Acq Crude cost	2.66	2.89
Composite Refiner Acq Crude cost	2.59	2.84
Saudi Arabia FOB	2.59	2.81
Saudi Arabia Landed	2.37	2.88
OPEC countries FOB	2.59	2.79
Brent	2.45	2.55

Figure 6: Monthly and Annual Averages of Global Crude Oil Prices in US$ and Euro



V. Conclusion

All evidence seems to support the notion that the TPZ framework was a credible representation of oil prices most of the 18 year period 1986 - 2003. The price range was the result of a pure strategy Nash equilibrium, a politico-economic framework supported by oil importing nations (led by the United States) and OPEC (led by Saudi Arabia). The result was generally stable prices in a mutually acceptable framework. Our proposed time periods are supported by the Chow test that proves that oil prices exhibited structural change in 1986 and that prices in the two periods 1986 – 1997 and 2000 – 2003 are not structurally different once you correct for inflation.

We showed that OPEC behaved as a loose political cartel aiming to dampen fluctuations in global oil prices while maintaining satisfactory oil revenues to its members. Saudi Arabia varied its oil production and subsequently OPEC's oil production to interact with global crude demand and uphold the TPZ. Oil prices were allowed to float within the target price zone; however when prices moved outside the range, the OPEC cartel came into play and production was changed to force prices back into the zone.

It may be that OPEC production capacity utilization has limited impact on prices unless it reaches above 95%. As OPEC's excess production capacity approaches zero, oil prices may increase dramatically until either global oil demand eases, new non-OPEC production comes on line, or new OPEC production capacity is added.

The introduction of the Euro has apparently impacted global oil prices earlier in the decade. Since the introduction of the Euro in 2000, and for all crude types, Euro based oil prices were more stable than US dollar based ones. In the three years 2001 –

2003, the nominal annual averages of global crude oil prices have been stable at around €25.5 (€25.64 in 2001, €25.34 in 2002, and €25.49 in 2003; only in 2004 did it rise to €29.78). However, it is unclear how the Euro affects current dollar denominated oil prices.

In the last few years, monthly average oil prices have risen well beyond the TPZ. This is due to an increase in world oil consumption (led by an increase in demand by China and India) coupled with a sharp reduction in excess supply capacity in oil producing countries. Other factors such as the weakened US dollar in 2003 and 2004, limited refining capacity, and turmoil in the Persian Gulf also contributed to the problem. It remains for the future to determine whether a new TPZ will develop that will guarantee oil producers satisfactory returns without damaging the global economy.

REFERENCES:

Adelman, M.A. "World oil production & prices 1947-2000." *The Quarterly Review of Economics and Finance*, 2002, 42, pp. 169-191.

Adelman, M.A. "Political Economy of OPEC" *Dialogue*, March 2005, 13(1), p. 7.

Ahrens and Sharma. "Trends in Natural Resource Commodity Prices: Deterministic or Stochastic?" *Journal of Environmental Economics and Management*, 1997, 33, pp. 59-74.

Bahree, Bhushan and Warren, Susan. "*OPEC Seek High Oil Prices to Offset Weak Dollar --- Cartel May Abandon Price Cap to Take Advantage of Strong Demand by U.S.*" Wall Street Journal, 4 December 2003, p.A1.

Bakhtiari, A.M. Samsam. "The price of crude oil" *OPEC Review*, March 1999.

Barsky, Robert B. and Kilian, Lutz. "Oil and the Macroeconomy since the 1970s" *Journal of Economic Perspectives*, Fall 2004, 18(4), pp. 115-134.

Brown, Stephen P.A.. "Oil and the US Macroeconomy" Federal Reserve Bank of Dallas. Presented at WEAI annual meeting. July 2, 2004.

Chapman, Duane and Khanna, Neha. "World Oil: the Growing Case for International Policy." *Contemporary Economic Policy*, January 2000, 18(1), pp.1-13.

Chapman, Duane and Khanna, Neha. "An Economic Analysis of Aspects of Petroleum and Military Security in the Persian Gulf." *Contemporary Economic Policy*, October 2001, 19(4), pp. 371-381.

Griffin, J.M., "OPEC behavior: a test of alternative hypotheses." *American Economic Review*, 1985, (75), pp. 954 - 963.

________ . "*Drowning in Oil*" Economist, 3 June 1999, 350(8109), p.18.

Gujarati N. Damodar, "*Basic econometrics.*" McGraw-Hill/Irwin. Fourth edition, 2003, pp. 275-276.

Hammoudeh, Shawkat. "Oil Price, Mean Reversion, and Zone Adjustment." *Southern Economic Journal*, April 1996, 62 (2).

Horn, Manfred. "OPEC's optimal crude oil price." *Energy Policy*, 2004, 32, pp. 269-280.

Jones, D.W., Leiby, P.N., and Paik I.K. "Oil Price Shocks and the Macroeconomy: What Has Been Learned Since 1996" *The Energy Journal,* 2004, 25(2), pp. 1-32.

Kaufmann, Robert K. Dees, Stephane Karadeloglou, and Pavlos Sanchez Marcelo. "Does OPEC Matter? An Econometric Analysis of Oil Prices" *The Energy Journal,* 2004, 25(4), pp. 67-90.

Kuper, Gerald H. and Soest, Daan P. "Does Oil Price Uncertainty Affect Energy Use?" *The Energy Journal,* 2006, 27(1), pp. 99-118.

Mazraati, M. and Tayyebi Jazayeri, S.M. "Oil price movements and production agreements" *OPEC Review,* September 2004, 28 (3), pp. 207-226.

Ramcharran, Harri. "OPEC's production under fluctuating oil prices: further test of the target revenue theory." *Energy Economics*, 2001, 23, pp. 667-681.

Ramcharran, Harri. "Oil production responses to price changes: an empirical application of the competitive model to OPEC and non-OPEC countries." *Energy Economics*, 2002, 24, pp. 97-106.

Romero, Simon. "*OPEC Stresses Compliance With Quotas*" New York Times, 10 February 2004, p.8.

Smith, L. James. "Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis" *The Energy Journal,* 2005, 26(1), pp. 51-82.

Tang, Linghui and Hammoudeh, Shawkat. "An empirical exploration of the world oil price under the target zone model." *Energy Economics*, 2002, 24, pp. 577-596.

Wirl, Franz and Kujundzic, Azra. "The impact of OPEC Conference outcomes on world oil prices 1984-2001." *The Energy Journal*, 1 January 2004, 45(1).

Yergin, Daniel. "*The Prize: The Epic Quest for Oil, Money, & Power.*" Simon and Schuster. 1992, pages 755-758.

VI- Appendix Evaluating Several Crude Oil Price Series

In this study, we have used US composite refiner acquisition nominal prices to test our hypothesis.[24] We noted that this series reflects 26% of world oil use and more than 38 different international sources of crude oil. In the following analysis, we will examine the monthly and annual price variability and correlation among the various benchmark series in nominal and real value and find the one that is the most representative. The most commonly used benchmarks in oil research are US refiner acquisition (imported, domestic and composite), Saudi Arabia (landed and FOB), OPEC (FOB), Brent and WTI.

The average monthly and annual standard deviation is calculated for all the above crude oil price series and presented in Table 9. The OPEC FOB exhibits the least variance both in the monthly and annual standard deviation whereas the WTI has the highest annual standard deviation. The US refiner acquisition cost which purchases oil from different sources including WTI and OPEC FOB has a domestic standard deviation close to the WTI and an imported standard deviation close to the OPEC FOB. The

Table 9: Monthly and Annual Standard Deviation for Different Crude Price Series

	1986 - 2003 US $	
	Monthly St. Dev	**Annual St. Dev**
Domestic Refiner Acq Crude cost	5.31	4.73
Imported Refiner Acq Crude cost	4.92	4.31
Composite Refiner Acq Crude cost	5.06	4.45
Saudi Arabia FOB	5.58	4.65
Saudi Arabia Landed	5.23	4.55
OPEC countries FOB	4.60	4.14
WTI	5.38	4.91
Brent	5.30	4.65

[24] Kuper and Soest, in their recent study, use US refiner acquisition cost for imported oil.

composite refiner acquisition cost averages this deviation representing a better proxy to the different price series.

In Table 10, we compare the standard deviation of the various crude price series both in real and nominal prices in the time period 1986 – 1997. The real prices exhibit much higher standard deviation than the nominal ones for all the crude price series under study.

Finally, we regressed each price series against each of others. The resulting coefficients of determination (the R squared values) are reported in diagonally symmetric Tables (11) and (12) for annual and monthly averages. As the two tables show, the prices of the several crude types are all highly related, and the imported and the composite refiner acquisition averages have the highest R squared values with respect to the other series.

Table 10: Comparing Nominal and Real Oil Prices for the Different Crude Price Series

	Nominal Prices 1986 - 1997 St. Dev	Real Prices 1986 - 1997 St. Dev
Domestic Refiner Acq Crude cost	2.37	2.81
Imported Refiner Acq Crude cost	2.30	2.83
Composite Refiner Acq Crude cost	2.32	2.80
Saudi Arabia FOB	2.69	3.04
Saudi Arabia Landed	2.57	2.93
OPEC countries FOB	2.30	2.85
Brent	2.74	3.22

Table 11: Coefficients of determination (R^2) matrix for the annual averages of various crude price series

Annual	Ref Dom	Ref Imp	Ref Comp	SA FOB	SA Land	OPEC FOB	Brent	WTI
Ref Dom	1							
Ref Imp	0.98	1						
Ref Comp	0.99	1	1					
SA FOB	0.9	0.93	0.92	1				
SA Land	0.96	0.98	0.98	0.98	1			
OPEC FOB	0.96	0.99	0.98	0.95	0.98	1		
Brent	0.94	0.95	0.95	0.97	0.97	0.97	1	
WTI	0.94	0.96	0.96	0.98	0.98	0.97	0.99	1

Table 12: Coefficients of determination (R^2) matrix for the monthly averages of various crude price series

Monthly	Ref Dom	Ref Imp	Ref Comp	SA FOB	SA Land	OPEC FOB	Brent	WTI
Ref Dom	1							
Ref Imp	0.98	1						
Ref Comp	0.99	0.99	1					
SA FOB	0.77	0.81	0.79	1				
SA Land	0.56	0.59	0.58	0.96	1			
OPEC FOB	0.92	0.97	0.95	0.88	0.95	1		
Brent	0.96	0.97	0.97	0.78	0.56	0.95	1	
WTI	0.97	0.97	0.97	0.8	0.57	0.95	0.98	1

In summary, the discussion in this appendix suggests that real oil prices have exhibited more variation than nominal prices. The US composite refiner acquisition price seems to have less variance, and higher coefficients of determination than other crude price series. In addition, the US composite refiner acquisition represents 26% of global daily oil consumption, and it includes oil from different sources and companies throughout the world. Therefore nominal US composite refiner acquisition cost seems to be the best proxy for global crude prices in the limited context of the analysis undertaken here.

OTHER A.E.M. WORKING PAPERS

WP No	Title	Fee (if applicable)	Author(s)
2005-26	The Politics of Oil and the Aftermath of Civil War in Angola		Kyle, S.
2005-25	A Strategy For Agricultural Development in Angola		S. Kyle
2005-24	New Directions in Development Economics: Theory or Empirics? A Symposium in Economic and Political Weekly		Banerjee, A., Bardhan, P., Basu, K., Kanbur, R., Mookherjee
2005-23	Spatial Inequality and Development: Overview of UNU-WIDER Project		Kanbur, R. and Venables. A.
2005-22	Oil and Politics in Angola		Kyle, S.
2005-21	A Framework for Scaling Up Poverty Reduction, With Illustrations from South Asia		Devarajan, S. and R. Kanbur
2005-20	Membership Based Organizing of Poor Women: Reflections After an Exposure and Dialogue Program with SEWA in Gujarat, India, January 2005		Editors: Chen, M., Jhabvala, R., Kanbur, R., Mirani, N., Osner, K. and C. Richards
2005-19	Oil Revenue, the Real Exchange Rate and Sectoral Distortion in Angola		Kyle, S.
2005-18	Minimum Wages and Poverty		Fields, G. and R. Kanbur
2005-17	Characterizing Distributions of Class III Milk Prices; Implications for Risk Management		Wang, D. and W. Tomek
2005-16	The Development of Development Thinking		Kanbur, R.
2005-15	Evolution of the Stock of Red Seabream in the Strait of Gibraltar: DEA-Malmquist Index and Stochastic Frontier Analysis		Espino, D., Fried, H., del Hoyo, J. and L. Tauer
2005-14	Examining the Effects of Deregulation on Retail Electricity Prices		Taber, J., Chapman, D. and T. Mount
2005-13	Turning a Blind Eye: Costly Enforcement, Credible Commitment and Minimum Wage Laws		Basu, A., Chau, N. and R. Kanbur

Paper copies are being replaced by electronic Portable Document Files (PDFs). To request PDFs of AEM publications, write to (be sure to include your e-mail address): Publications, Department of Applied Economics and Management, Warren Hall, Cornell University, Ithaca, NY 14853-7801. If a fee is indicated, please include a check or money order made payable to Cornell University for the amount of your purchase. Visit our Web site *(http://aem.cornell.edu/research/wp.htm)* for a more complete list of recent bulletins.