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Building a Consensus Forecast for Crude Oil Prices

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BUILDING A CONSENSUS FORECAST FOR CRUDE OIL PRICES

THESIS

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Abstract

Skyrocketing fuel prices have stressed the Department of Defense's budget in recent years. In 2001 the DoD spent $4.7 Billion on fuel with the Air Force consuming $ 2.7 Billion (GAO, 2001). These figures have grown over due to these increases as well as the increased flying ours to support the Global War On Terror. In fact, the Fiscal Year 2007 budget has already been increased by $1.1 billion, or 1% of the total budget, to accommodate the increased price of fuel (SAF/FMB, 2006). Current forecasts of this resource have yielded poor results, impairing the DoD's ability to budget this critical expense. Further because the forecast are poor, strategic hedging strategies cannot be effectively employed. Because fuel is a significant portion of aircraft operations and maintenance cost it should be considered in the acquisition of new systems, but the current forecast have not provided the accurate data required.

Current forecast available to the DOD were examined, and compared to two econometric structural forecast models. The performance of these structural models was then compared to the benchmark forecasts for energy provided by the Energy Information Agency. A consensus price forecast was constructed from these alternative forecasts.

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BUILDING A CONSENSUS FORECAST TO PREDICT FUTURE CRUDE OIL PRICES

I. INTRODUCTION

Overview/Background

Petroleum and its products are vital to maintaining a vibrant modern economy. It is a factor in virtually every aspect of production, with far-reaching impact in not only business but also in the personal lives of consumers. The price of oil plays a role in the selection of which car we buy, what trips we can afford to make, as well as playing a vital role in many business decisions. Currently, the Energy Information Agency (EIA) forecasts U.S. demand for crude oil to increase from 15.6 million barrels per day (mb/d) in 2005 to 18.1 mb/d in 2030 (AEO, 2006). Clearly oil is important to our economic security.

The Department of Defense (DoD) is a major consumer of petroleum in the United States. The DoD fuel sales totaled $4.7 billion in fiscal year 2001, with the Air Force consuming approximately $2.7 billion in fuel. This means the price of fuel is an important budgetary concern for the DoD, and critical to our national security.

The United States Air Force, as it builds a strategy to provide for the protection of the United States and its interests, will continue to assess not only today's price for fuel but also future prices. This is especially true as it makes decisions in three areas of concern: acquisition, budgeting, and hedging strategies in the purchase of petroleum reserves.

Problem Statement

The volatility in crude oil prices has had a profound impact in every aspect of the American economy. This has resulted in difficulty in preparing long-term budgets and planning. Decisions such as hedging against future fuel prices are also heavily reliant on accurate forecasts. The DoD has not been exempt from these problems, but has faced additional complications as it transitions the fighting force to protect the U.S. against modern threats, and as it fights the Global War On Terror.

Research Question

This thesis seeks to answer the following research question:

How can the USAF better predict long-term fuel prices to enhance the transformation of the forces to face modern threats, improve financial planning and improve logistics planning?

To answer this question the following investigative questions will be addressed:

1. What forecasts have historically been most accurate at predicting fuel prices?
2. What variables can be used in a reduced form forecast to improve forecast reliability?
3. How can the most accurate forecast be combined into a consensus forecast?
4. Will a parsimonious and theoretically simple model out perform more heavily parameterized models?

Scope and limitations

The scope of this thesis is limited to forecasting crude oil. While many factors are used to construct a forecast of this nature, factors other than the price of oil will not be forecasted where reasonable forecast exits. This includes production quantities, prices for substitutes and oil products and the economy.

Thesis Outline

This thesis will review all applicable literature associated with forecasting crude oil as well as the statistical tools used to analyze the forecasts in Chapter II. Chapter III will explain the methodology used to conduct this research. The results will be discussed in chapter IV. Finally, Chapter V will summarize the first three chapters and findings from the research. Additionally, Chapter V will discuss the conclusions and make recommendations for follow-on research.

II. LITERATURE REVIEW

This chapter begins with a review of the history of crude oil production beginning in the 1930s. It goes on to address the concerns about incipient supply constraints. This is followed by an explanation of the statistical tools used to evaluate forecast accuracy and concludes with an explanation of forecasting methods and models used to forecast oil prices.

Oil History

The history of oil production since the 1930s can be divided into two time periods: early expansion, and the post 1973-1974 oil embargo. Before the embargo, oil prices were very stable, and had a notable albeit modest downward trend. Since the embargo, prices have been subject to several shocks that have caused a great deal of volatility in oil markets. Figure 2-1 illustrates the real price of crude oil from 1950 to 2004.

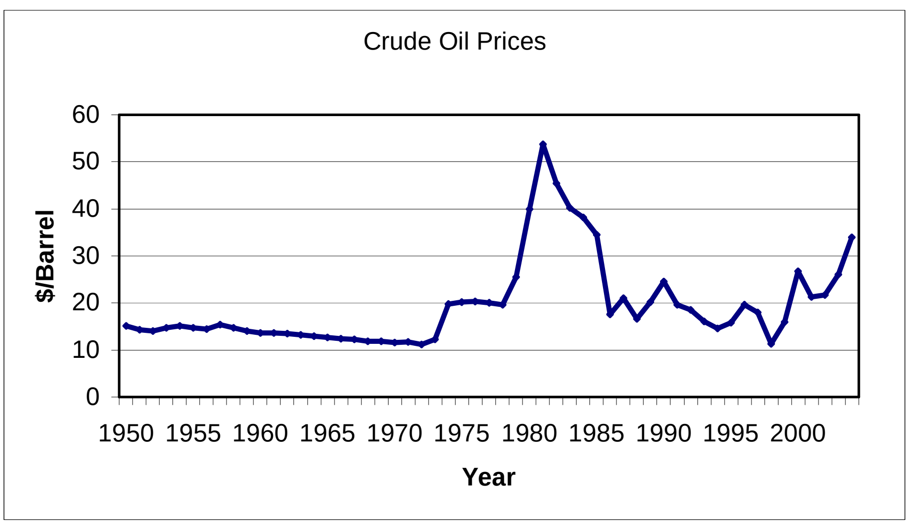

Figure 2-1: Crude Oil Prices 1950 – 2004 (AER, 2005, T5.18)

Early Years

During the early years the world enjoyed stable oil prices and rapid expansion in demand; however, the seeds that eventually became the volatile oil prices of today were sown during that time. During this time most of the growth in demand was met by production in the Middle East (Cremer, 1991). As the world became dependant on cheap oil found in the Middle East, the underlying market was changing.

Initially the oil markets were dominated by a few big oil companies, or “majors,” which enjoyed large profits and little serious competition. As a result, an oligopoly was formed and prices were controlled largely by informal agreements. Unfortunately, this left the governments of the oil-producing nations out in the cold. The rents they received for the oil extracted in their countries were largely dictated to them, and they had little control over their fate. But, the large profit margins invited a swarm of independent oil companies to invade the market, offering better terms to the governments in an effort to break into the market (Cremer, 1991).

During this time, Middle Eastern countries received a royalty on the oil produced within their borders. This meant that government revenues were tied to volume, regardless of price (Cremer, 1991). But in the 1950s the oil companies began to share the profits and risk of the oil markets with the governments of oil producing nations. This was not an easy task given that the oil companies were large, vertically integrated firms and the spot markets a small share of production. As a result the agreement was that the “posted price,” a simplified calculation of the oil sold in different markets around the world, would be used. Under this new agreement government revenues were still tied to production, but price was becoming a more important consideration in determining levels of production (Cremer, 1991).

Formation of OPEC

Increased competition caused the oil companies to cut market prices in the late 1950s. The reduction in government revenues prompted five oil-producing nations to form the Organization of Petroleum Exporting Countries (OPEC) (Cremer, 1991). The original members of this fledgling cartel were: Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela. Since that time the membership has grown, and today the eleven member countries produce about 40 percent of the world's oil (EIA IPM Appendix A).

Initially, OPEC failed to reverse the trend in the market price for oil. Prices fell throughout the 1960s to an all time low on 1969. Throughout this time the big oil companies held the production reins (Cremer, 1991). At least one prominent analyst believes the amazing demand growth for OPEC oil, 10 percent annually, was technically unsustainable (Gately, 1995). Leading this demand growth were surging European and Japanese markets and a peaking U.S. market (Cremer, 1991).

However in early 1970s, OPEC nations began to exert pressure on the oil companies. During this time the governments became partial owners of the operating companies that, until then, had been owned by foreign multinationals (Cremer, 1991). OPEC's ability to control oil production was growing and the stage was set for a new era in the oil markets.

1973 Oil Embargo

In October 1973, King Faisal of Saudi Arabia and the other OPEC nations changed the world forever when Faisal waved his “Oil Sword” in response to the US support of Israel following an unprovoked attack by Egypt during the Yom Kippur War (Simmons, 2005). Faisel enacted an embargo on all oil shipments from Saudi Arabia to the US and the Netherlands. This coupled with the reduction in oil production caused a sharp spike in oil prices that was not fully felt until 1974, when OPEC raised the price of oil to over $11 (Simmons, 2005; Cremer, 1991). While the embargo was lifted in March 1974, OPEC had realized its control of oil prices and the enormity of its potential revenues. In 1973 OPEC generated about $137 billion in oil revenues. But as a result of the increased prices OPEC generated over $410 billion in oil revenues while reducing its production by about 300,000 barrels per day (Cremer, 1991).

In the US, the price effects of the embargo were exacerbated by President Nixon’s price control program. This program limited fuel price increases in an effort to mitigate soaring inflation, which began in March 1973. It was during this time that the US called for voluntary rationing, banned sales of gasoline on Sundays and approved the Trans-Alaskan oil pipeline designed to carry 2 million barrels per day. At that time, the US consumed about 6 trillion barrels of crude oil daily (Trumbore, 1999).

Following the Oil Embargo, prices remained high and demand for OPEC oil grew only slightly (Gately, 1995). It was during this time that many OPEC countries began to cut production, seemingly unilaterally and without expectation of other member nations reciprocating. Saudi Arabia announced that it would limit production to 8.5 mb/d, a dramatic reversal of the previous goal of 20 mb/d before the embargo (Cremer, 1991).

1980 Price Spike

The 1978 Iranian revolution also had a dramatic impact on global oil production (Gately, 1995). As part of the revolution, the oil workers went on strike in the fall of 1979. By December Iranian oil stopped flowing (Cremer, 1991). This resulted in the landed price of oil from the region to increase from $13.85/barrel in 1977 (nominal $) to $20.42/barrel in 1979 (AER, 2005, T5.19). The strike ended in the spring of 1979 but production was only at slightly over 50 percent of the pre-revolutionary rates. Before the revolution, Iran produced 20 percent of OPEC's total production, at a rate of about 5.6 mb/d. After the revolution, Iranian production fell to 3.1 mb/d in 1979 (Cremer, 1991).

OPEC's lack of responsiveness coupled with consumers stockpiling oil caused prices to continue to drift upwards following this price shock (Gately, 1995). OPEC voted to raise the ceiling on oil prices, but they lacked a unified vision for the price structure. While the official ceiling was $23.50, Saudi Arabia held to a much lower $18/barrel. The spot price continued to rise, and efforts to unify OPEC's position failed until 1981 (Cremer, 1991).

Finally, in September 1980, Iraq attacked Iran and occupied much of its oil producing region. This bitter conflict lasted until 1988 and reduced oil production from two of OPEC's largest producers. Iranian production dropped from 3.1 mb/d in 1979 to only 1.3 mb/d in 1981 and Iraq dropped from 3.4 mb/d in 1979 to 1 mb/d in 1981. While Iranian production did increase in 1982, it was not until after the war that it regained production to over 3 mb/d. Iraq, on the other hand, has not seen production over 2.6 mb/d since that time (AER, 2005, T4.1a).

In 1981 OPEC made yet another attempt to gain control of oil prices, with Saudi Arabia raising its price to $34. Additionally, OPEC cut production in an attempt to keep prices elevated and set specific differentials for the various grades of crude oil. But this ended when British National Oil Company (BNOC) cut the price of North Sea oil. Nigeria responded by cutting its price unilaterally. This caused the cartel agreement to collapse (Cremer, 1991).

With this breakdown in price controls OPEC tried to gain control of the production in member countries in March 1982. This is significant because it is the first time OPEC behaved like a textbook cartel. But this met with little success and by the end of 1982 the production limits set by mutual agreement were being exceeded by some 2 mb/d. This caused a glut in the oil market. In February 1983 BNOC cut the price of North Sea oil; Nigeria responded by undercutting BNOC's price (Cremer, 1991).

Throughout this time frame Saudi Arabia was the swing producer, adjusting production to keep a stable price. As such they had no production quota, but matched the market demand at the set price. The difference between the OPEC's target total production and the quotas for all other members was 7 mb/d, and that was assumed to be Saudi Arabia's production quota. This meant that the kingdom would need to absorb increases in non-OPEC production, and the resumption of exports from Iran and Iraq. It also meant that they would need to compensate for any cheating in OPEC nations. This led Saudi Arabia to cut production year after year. Even still, the price of oil fell steadily until in October 1984 Saudi Arabia was finally given a quota. But this was not enough to keep prices elevated. Additionally, several countries were over-producing, causing Saudi

Arabian production to fall to 2 mb/d in the summer of 1985. This was 8 mb/d below 1981 production rates, and Saudi Arabia had been pushed to the limit (Cremer, 1991).

Price collapse 1985

Pressed with falling oil prices and declining production, King Fahd of Saudi Arabia issued an ultimatum: Saudi Arabia would claim its share of OPEC production. If the members of OPEC did not cut production prices would fall. Fortunately for the rest of the world, prices fell. The nominal price of Saudi Arabian Light Sweet Crude in 1985 was $29 per barrel; by 1989 the price had fallen to $13.15. And OPEC's last great push to inflate oil prices had died (Cremer, 1991).

DESERT STORM

In August 1992 Iraq once again turned on one of its neighbors, this time the much smaller and weaker Kuwait. This prompted an immediate reaction from the international community. An embargo was placed on Iraqi oil exports, cutting off a significant portion of the gulf region's potential exports (Simmons, 2005). As a result Iraqi production dropped from 2.8 mb/d to about 300 tb/d and Kuwaiti production dropped from 1.7 mb/d to 190 tb/d (AER, 2005, t4.1a)!

The loss of production from both Iraq and Kuwait initially caused oil prices to soar. But Saudi Arabia moved quickly to increase its production from about 5.3 mb/d before the invasion to more than 8 mb/d. The speed at which Saudi Arabia did this illustrated the existing excess capacity. But there is some concern over the effect such high production had on the giant oil fields (Simmons, 2005).

OPEC: Trouble in Paradise?

The 2005 EIA's Annual Energy Outlook has forecasted OPEC to increase production from about 30.2 mb/d in 2002 to over 50.3 mb/d in 2025, with most of the growth, 17.6 mb/d, coming from the Middle East. This is crucial if the global production of crude oil is to grow from 76.6 mb/d to over 114 mb/d in 2025 (AEO, 2005). Without this production growth from the Middle East, it has been argued, the price of oil will grow rapidly.

This very aggressive prediction may prove difficult to attain. In his book *Twilight in the Desert*, Matthew Simmons outlined three reasons OPEC in general and Saudi Arabia in particular may not be able to increase production to these unprecedented levels: political, industrial, and limited reserve levels. While the focus of his work was on Saudi Arabia's reserve levels, he did provide some interesting insights on the other reasons.

Saudi Arabia is a nation forged in war, and initially comprised largely of nomadic peoples sparsely populated over the vast deserts. Over the last half-century the population has exploded and the nomadic herdsmen have settled in cities. In 1980 Saudi Arabia's population was 9.4 million, but by 2003 the population had grown to 24.2 million (Simmons, 2005). Put another way, Saudi Arabia's population grew by 158 percent while the world population grew by about 43 percent. At the same time the nation's GDP has only grown by about 41 percent, with most of this growth occurring after 1990. As of 2003 Saudi Arabia's per capita income was only $8,400. This places their per capita income at 46th in the world (EIA IEA 03 tb.2c).

While Saudi Arabia has strong petroleum and petrochemical industries, it has little other employment opportunities. These industries cannot fully employ the nation's population, leading to rampant unemployment. The government needs to greatly subsidize many staples necessary for modern life such as like water, health care, gasoline, and electricity. As the population grows a greater strain is placed on the governments already stretched budget. The government is already examining expenditure reductions (Simmons, 2005).

The second reason Saudi Arabia may not be able to increase its production as rapidly as the EIA forecast suggests is industrial constraints. In 1980 Saudi Arabia’s production of crude oil averaged 9.9 mb/d. Over the next several years this rate fell until in August 1985 oil production was at 2.3 mb/d. Since then production has increased steadily, and in 2005 production averaged between 9.5 and 9.6 mb/d. The marginal cost of increasing production during those years most likely would have been much smaller than in the coming years as much of the infrastructure needed to produce, store and distribute oil existed. This hypothesis is very testable, but much of the information needed directly to test this are considered a state secret (Simmons, 2005).

Most of Simmons’ text dealt with the heath of the giant oil fields, and his belief that these fields are in the twilight of their lives. In general he states that years of overproduction have dramatically shortened the productive life of the mainstay of Saudi oil, and in the near future the oil from the kingdom will stop flowing. Again this hypothesis is testable, but much of the primary data is not available. This leaves researchers to examine the limited reports available from the kingdom (Simmons, 2005).

<u>The Scarcity of Oil</u>

Most people believe that there is only a finite amount of oil on Earth (Cremer, 1991). As a result, prognosticators have predicted the total depletion of the world’s oil supply for a long time. Fortunately, these luminaries have been almost universally wrong in there assertions, often with magnificent orders of magnitude! Potentially this could play a significant role in modeling the globe's energy, depending on the time horizon for this to occur. Several obstacles make determining the exact reserves remaining difficult, if not impossible. First is the paradox observed by Adelman (1972). The Persian Gulf had 42 billion barrels in proven reserves in 1950, by 1971 the reserves had grown to 367 billion barrels, and in 1988 the region had 552 billion barrels. Between 1950 and 1971 some 47 billion barrels of oil were extracted, and 98 billion barrels were extracted between 1971 and 1988. This can be explained three ways: as oil prices increase economically feasible extraction of oil also increases; the technology to extract oil has improved; and not all reserves in the world are known (Cremer, 1991).

Formal Forecasting of Petroleum Prices and Output

This section begins with a discussion on econometric forecasting and of the types of forecasting models in use today. It then moves to a discussion of the application of some of these types of models. It then outlines some of the mathematical tools used in forecasting, and concludes with a discussion of consensus forecasting.

Econometric Forecasting

Econometric forecasting makes extensive use of regression analysis to build causal models to predict the future. One of the earliest models of this form was built by Charles Sarle in 1925. In his paper, Sarle forecasted the price of hog with reasonable accuracy, and won a Babson Prize for his efforts. Unfortunately, this work was discounted and few such models followed for many years. In the 1950s, the work re-emerged and has since gained popularity (Allen, 2001).

Because there is a large range of choices as to the variables selected, the form of the model and even the number of equations included, there is not one single overarching strategy to build a model. As with all forecasting, the goal should be a model that is as simple as possible. It should only be as complex as necessary to achieve accurate results. Frequently, though, models prove effective in sample but provide poor forecasting out of sample. One of the chief reasons for this is reliance of forecasted values. An independent variable should only be used when its value is known or can reasonably forecasted (Allen, 2001).

Forecasting Models

Oil pricing models primarily fall into one of two paradigms: intertemporal optimization and behavior simulation. Each of these has distinct strengths and weaknesses.

The intertemporal optimization has its roots from Hotelling's model of depletable natural resources and has dominated the theoretical literature without finding much in the way of practical use (Powell, 1990; Gately, 1995). This method has three assumptions: the owner has perfect knowledge, perfect foresight, and the owner will seek to maximize net return on the investment. The rent – or price less marginal cost of production – on the resource is discounted as the time moves toward the horizon, and the return on investment is the sum of the discounted rents. This provides the modeler with a representation of the intertemporal equilibria for the agents (Powell, 1990).

This type of modeling has the distinct advantage of offering an economically rational explanation of the actors in the model. But, it has some very serious drawbacks. First, perfect foresight and knowledge are highly unrealistic. For this to happen oil producers would need to know and understand the exact level of world reserves, the rate of technological developments for extracting and distributing oil, current and future demand for oil and the correct discount rate. These models also tend to be sensitive to price and the discount rate, as well as the availability and pricing of substitutes (Powell, 1990). This means that the models are only useful if a narrow set of assumptions are met (Gately 1995). These models also do not incorporate non-economic variables into the model very well. This means that objectives other than financial returns cannot be incorporated in the model. Finally, these models do not explain how the market moves from disequilibrium to equilibrium (Powell, 2005).

The second major type of oil model is the behavior simulation model. This paradigm incorporates System Dynamics and the bounded rationality schools of thought into a single class of models. As a result, these models embrace the uncertainty of the market and move from disequilibrium to disequilibrium much like a clock pendulum. To do this the model uses heuristic rules imposed by decision-makers. This produces sub-optimal results for the producers, but the users of this type of modeling see that as a strength rather than a weakness. Additionally, this model is solved recursively, beginning with the current prices. This means they can illustrate how the market may evolve over time. Finally these models illustrate effects of non-economic variables better (Powell, 1990).

This type of model has been criticized for three reasons: the statistical relationship deteriorated after 1985, it requires the production capacity path be assumed and it is inappropriate to assume the capacity path independent of the price path. Nevertheless, this type of model is used by the National Energy Modeling System (NEMS) to forecast international oil prices (Powell, 1990).

Elasticity Simulation Model

Dermot Gately defined a simulation model based on the elasticity of supply and demand for oil in 1995. This model ties in OPEC production growth and the growth of world income together. By varying OPEC production as a ratio of world income growth various price paths could be examined. In particular Gately examined three scenarios: OPEC production growing half has fast as world income, OPEC production growing as fast as world income and OPEC production growing twice as fast as world income. For each of these scenarios he presents an optimistic, reference and pessimistic case from OPEC's point of view (Gately, 1995).

This model was updated in 2001 to test the economic incentives for OPEC to increase production at the rate required to meet the International Energy Agency (IEA) and EIA production forecasts. This new model tested the effects of OPEC production growth at a flat rate through 2020. The rate of production was varied from 1 percent to 4 percent annually, and the resulting discounted oil revenues were compared. Based on his simulations, OPEC would likely receive the greatest discounted earnings by increasing production at a rate of no more than 2 percent per year (Gately, 2001).

Gately has also extended this analysis in a pending article in the *Energy Journal*. In this article he examined the effects on OPEC's revenues based on OPEC increasing to capture a larger share of global oil market, maintain its share of the oil market, or decrease production growth and accept a small portion of the world oil production. He also examined the effects of potential for disunity within OPEC. To test these effects he divided OPEC into two groups: Core and Non-Core members. The Core members were Saudi Arabia, Kuwait and the United Arab Emigrants (UAE). Different production paths were then examined for both groups and the relative income from each path compared (Gately, 2003).

He concluded that production increasing OPEC's share of the world's oil production result in a lower payoff for OPEC's members. In regard to the disunity among OPEC members he found that they were in a zero sum game. If either group could be certain that the other would increase production slowly, a fast increase in production would be profitable for that group. But if either group does increase production at a faster pace, the other will likely move to match that pace. As a result, he believes that the incentive is to increase production at a slower pace (Gately, 2003). Of course, this does not consider a scenario in which a group cannot increase production for some reason.

Target Capacity Utilization Model (TCU)

The TCU model has become the dominant simulation model. The TCU model has two basic assumptions: OPEC is the residual supplier of oil on the global market, and it bases the price of oil on targeted production capacity (Powell, 1990). Since 1980 many examples can be seen where OPEC, or members of OPEC, have acted as the swing (or residual) producer. During the early 1980s Saudi Arabia continuously cut production in an effort to inflate prices. Also, in August 1990 Saudi Arabia increased production to stabilize prices on the world oil market when Kuwaiti and Iraqi oil production stopped. Additionally, OPEC has acted several times during that timeframe to set oil prices or OPEC production or both (Simons, 2004). These assumptions seem plausible. This type of model was used in seven of ten models in the 1982 Energy Modeling Forum, and has been used the EIA forecast as recently as 1985 (Powell, 1990; Gately, 1995).

To initiate this type of model, a set of rules are assumed to change oil prices based on OPEC production capacity utilization. In one of the earliest models of this type, Gately, Kyle and Fischer set the rules to decrease the price by 5 percent, unless utilization was below 75 percent and last year's production was less than two years ago, or utilization is above 85 percent and last year's levels exceeded production two years ago. In the former case prices would be dropped by 20 percent, and in the latter case prices would be raised 15 percent (Gately, 1977). But while the discounted net present value might show what would be the best set of rules for OPEC to use, it says nothing about what rules they will use in the future (Powell, 1990).

Models of this type have come under sharp criticism. In 1990 Stephen Powell tested this form of model extensively. With respect to the price change relationship to capacity utilization he found that the markets did not follow the EIA projection from 1984 to 1990, and the relationship depended heavily on one's interpretation of capacity. The results varied significantly based on this interpretation. Further, when the model was placed in a simulation the resulting fluctuations had no relationship to a profit-maximizing outcome. Powell did acknowledge that there are many reasons to model energy and without knowledge of exactly how it would be used any crititque would be limited (Powell, 1990).

National Energy Modeling System

The Department of Energy's Energy Information Agency administers the National Energy Modeling System (NEMS) "to project the energy, economic, environmental, and security impacts on the United States of alternative energy policies and of different assumptions about energy markets." This model used a modular structure that enables different segments of the US economy to the evaluated, along with the interaction these segments have with each other. As such this model forecast much more than just the price of crude oil (EIA, 2003). Figure 2-2 displays an overview of NEMS.

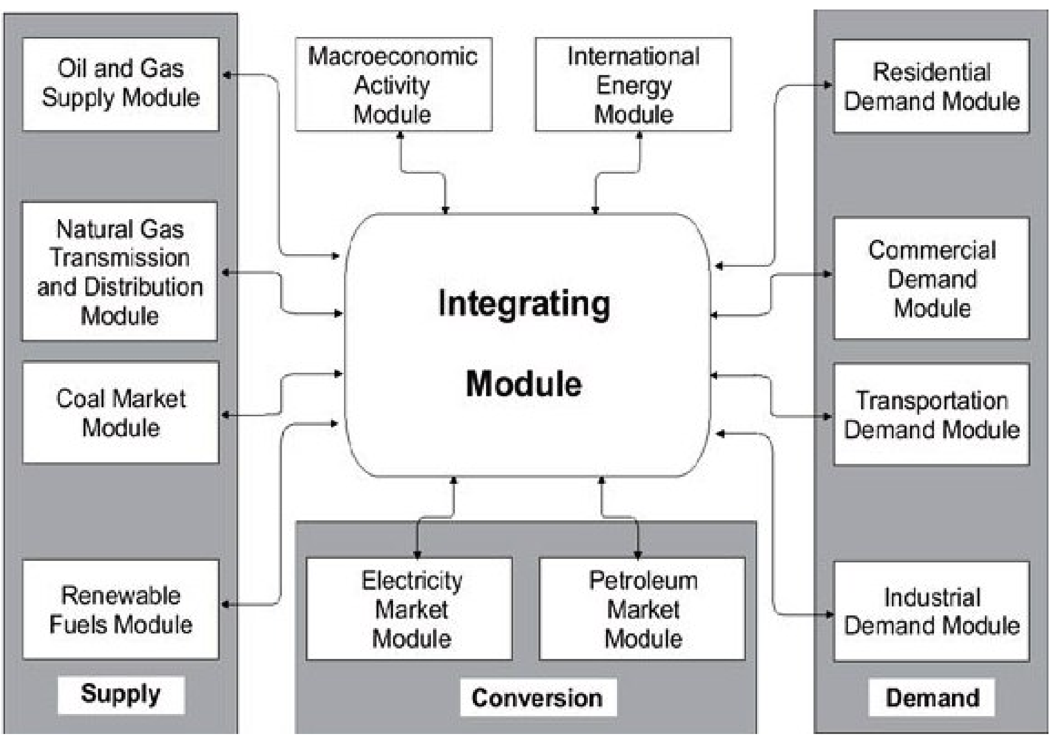

Figure 2-2: Overview of NEMS Architecture (EIA, 2003)

According the NEMS 2003 overview,

> “NEMS represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine Census divisions, by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior.” (EIA, 2003)

The price of crude oil is forecasted in the International Energy Module. This module is of greatest interest to this research. Table 2-1 list all the inputs and outputs of this module. The price of crude oil is an input to all modules, and therefore is critical to all forecast in NEMS. But, as Table 2-1 illustrates, this module relies on inputs from other modules in NEMS. One of the assumptions for this module is that OPEC will increase production to meet global demand. This means that the different forecasted price paths are a result of varying production growth from OPEC. However, this module also has the ability to forecast OPEC production given a price path as well. (EIA, 2003)

Table 2-1 International Energy Model Inputs/Outputs (EIA, 2003)

IEM Outputs	Inputs from NEMS	Exogenous Inputs
World oil price Crude oil import supply curves Refined product import supply curves Oxygenate import supply curves	Domestic crude oil production Domestic natural gas liquids production Domestic gas-to-liquids production Domestic coal-to-liquids production Domestic other liquids production Domestic refinery gain Domestic product supplied GDP price deflators Domestic crude oil imports Domestic refined product imports Domestic oxygenate imports Domestic unfinished oils imports	OPEC production capacity path Reference non-U.S. oil supply and demand Non-U.S. economic parameters Base import supply curves for crude oils, refined products, and oxygenates

Ultimately, the world oil price is derived in part from inputs provided by other modules that in turn rely on the world oil price as an input. This requires the system to cycle through many iterations before the model settles on a forecast. This poses a problem if any of the underlying assumptions or exogenous inputs is incorrect, but this is true for any model. OPEC’s production of crude oil is an exogenous input to the model, so it is critical to the model and subject to scrutiny. If OPEC fails to meet the production forecast input to this module, whether by design or not, the forecast accuracy will be negatively affected. Further, it can easily be argued that oil prices will effect OPEC production, but these are an exogenous input to the model (EIA, 2003).

Forecasting tools

Forecast performance can be measured in a variety of ways including: Mean Error, Mean Absolute Error, Mean Percentage Error, Mean Absolute Percentage Error (MAPE), and Mean Squared Error (MSE). Each of these measurements has their own strengths and weaknesses. Mean Error and Mean Percentage Error both use the raw error in the calculation error. As a result, they consider both the positive and negative errors and the result is most likely a much smaller error and most forecasters do not use these as the primary measurement of error.

MAPE is mean of the Absolute Percentage Error (APE) for each forecasted period. APE is calculated using the following formula:

$$APE = \frac{Y_t - F_t}{Y_t} * 100$$

This has the advantage of showing the relative size of the error as a percentage of time series data. This enables a comparison across multiple sets of data that may not have the same relative values. But for MAPE to have any meaning, the scale of the underlying data must have meaning. Additionally, MAPE can only be calculated if the actual values being forecasted cannot be equal to zero. MSE on the other hand does not provide any indication of the relative size of the error. But it is easier to handle mathematically. (Makridakis, 2004)

Consensus Forecasting

A consensus forecast uses several forecasts to build a more accurate prediction. This enables forecasts that use different methodologies and assumptions, and consider different factors to be combined giving a more comprehensive end product. The real challenge in building a consensus forecast is deciding which forecasts to included, and their associated weights. This requires the performance of each forecast to be measured and compared. Forecasts with robust performance are given more weight than those with lesser accuracy.

Summary

Obviously, a great deal goes into forecasting petroleum prices. Over the last 65 years several events have influenced the price of oil, often without warning or precedent. Further, the interplay between oil prices and other aspects of our economy make pinpointing a price difficult. Many complex, often intractable models have been built to forecast this precious commodity – with meager results. This limits their use within the DOD community. I will illustrate an extremely tractable and accurate forecast to solve this problem.

III. METHODOLOGY

Overview

This chapter outlines the data employed by this study followed by an explanation of how the most predictive variables were selected. Then goes on to address three forecasting models: an ARMA 4,4, and two reduced form models. It concludes with an explanation of how these forecasts along with the major forecasts were evaluated.

Data Selection

Reliable data is needed to build a strong forecast, and energy forecasting is no exception. The data selected all have a relationship with petroleum supply or demand. These relationships are explained more fully later in the thesis. Most data are obtained from the Energy Information Agency (EIA).

This study uses the Gross Domestic Product (GDP) Deflator to state all monetary data in real terms. A GDP deflator adjusts the GDP to remove that portion of the increase in GDP from inflation leaving only real growth.

Forecasting Methods

There are several methods to forecast the price of crude oil over the long term ranging from simple smoothing techniques to the complex models used by the US Department of Energy (DOE). Further, the variables used can also range greatly. This creates a very large pool of potential forecasts. Fortunately, many of the simple methods are not well suited to forecasting over a long period of time, and more methods can be eliminated because the data in this case is annual and does not require any special treatment for seasonality. For the purpose of creating the forecast as part of this study, two basic forecasting methods were employed: Autoregressive Moving Integrated Average (ARIMA) and Reduced Form Structural Model.

Autoregressive Integrated Moving Average

ARIMA uses past values of the data being forecasted and the moving average of error to generate predictions about the future. This type of forecast can be very accurate and can capture some of the natural fluctuations in the data but offers no explanation of why the dependent variable is changing.

To prepare the ARIMA forecast the Box-Jenkins methodology was used. This is a three-phase process: identification, estimation and testing, and finally application. The identification phase has two steps: data preparation and model selection. During data preparation the time series is transformed to stabilize the variance in the data and differenced to obtain stationary data as necessary. The estimation and testing phase also has two steps: estimation and diagnostics. During the estimation step the parameters of possible models are estimated and the best model is then selected using criteria such as Akaike's Information Criterion (AIC) or Schwarz Bayesian Information Criterion (SBIC). Then during the diagnostics step the residuals are analyzed to determine if they are White Noise. White Noise is attributed to pure random chance and displays no predictable pattern. If the residuals are not White Noise the modeler reverts back to step 2 in the first phase. Finally, in the third phase, Application, the model developed in the first two phases is applied to the data and a forecast is made (Makridakis, 2005).

Reduced Form

A reduced form or structural equation model is a representation of the underlying supply and demand curves in a given market. To do this the independent variables are selected to represent the supply and demand sides of the market, then applied in a regression equation to forecast what will happen in the market. The three basic assumptions for regression – normality of residuals, independence of residuals, and constant variance – apply to this type of model.

Variables for this model were selected to represent changes in the underlying supply and demand. I categorize these variables as: economic indicators, consumption, oil reserves, oil production, oil exploration and infrastructure, and current events. A complete list of variables tested is included in Figure 3-1. Before the variables were included in a regression equation, their predictive ability was tested and the correlation evaluated. Variables with poor correlation were discarded in favor of more predictive variables. Further, variables with p-values greater then 0.10 were also eliminated. The p-values were relaxed from the normal 0.05 because multicollinearity can cause inefficient estimates.

Consensus Forecast

A consensus forecast is a linear combination of the forecasts used. This is the same as a weighted average of the forecasts involved. The weights for the forecasts are calculated using the following equation:

$$w_i = \frac{1 \big/ \left|\bar{e}_i\right|}{1 \big/ \sum_{i=1}^{n} \left|\bar{e}_i\right|}$$

where $\left|e_i\right|$ is the absolute error. By definition the sum of the weights is 1.0. This provides the greatest weight to the forecast with the smallest mean error (Hammond, 2004).

Economic Indicators	High	Low	Average	Standard Deviation
GDP Deflator (First Difference)	5.08	0.18	1.63	1.2938
GDP (in 2000 chained dollars)	10755.7	2560	4150.2	1769.9
Consumption	High	Low	Average	Standard Deviation
Economic Sector consumption				
Electric	588318739	61534000	217778518	161272748
Transportation	7316602	2037208	4654141.2	1313080.6
Industrial	1950240	583251	1297207.2	353286.8
Commercial	272284	121339	207758.7	39975.5
Residential	557548	204078	382493.3	101490.3
Global Population	6372.8	2555.4	3887.7	910.0
US Population	293655	165931	205789.5	31614.3
Strategic Oil Reserves (SOR)	High	Low	Average	Standard Deviation
Days in reserve				
Percent SOR in Crude oil	70.4	2.1	48.34	20.15
Total Petroleum in SOR	41.1	0.6	24.95	12.81
Global Oil Production	High	Low	Average	Standard Deviation
OPEC Total	32922.3	17151	24922.3	4626.7
Global Total	68563.6	48986	61122.9	4878.7
Oil Infrastructure and Exploration	High	Low	Average	Standard Deviation
US Oil Wells drilled	413112	99410	19795.5	69647.8
Global Crude Oil Distillation Capacity	82258.3	47048.8	70942.9	9277.5
Percentage of Crude oil Distillation Capacity Used	1.0412	0.7210	0.8708	0.0847
Current Events*				
War				
OPEC Restrictive Policy				
Supply Capacity constraint				
Constant Oil Price Policy (1949 to 1970)				
Time*				
* No lags were considered for this data				

Figure 3-1: Independent Variables

IV. RESULTS

This chapter begins by outlining the ARIMA model constructed to forecast crude oil. It then goes on to outline the findings of the univariate analysis and outlining two reduced form models that perform well over the holdout set of variables. Finally, a consensus model is constructed.

Three forecast models were constructed; a naïve time series (ARMA) and two structural models. The structural variables were chosen based on the univariate correlation with oil prices at the beginning of the chapter. Additionally, the data was divided into two sets before any of the forecast models were built. The first set, or initiation data set, consisted of all data prior to 1994. This data was used to build the models. The second set of data, the hold-out set, was used to evaluate the model's predictive performance.

ARIMA

The ARIMA model that yielded the best results was an ARMA (3,1). This model produced an adjusted R^2 of 0.7896 and an Akaike's Information Criterion (AIC) of 139.7489 , and can be represented as $F_t = \theta + \beta(AR_{t-1}) + \beta(AR_{t-2}) + \beta(AR_{t-3}) + \beta(MA_{t-1})$ where AR is the autoregressive term and MA is the error term. The coefficients, as well as the associated standard error and t-test, are presented in table 4-1.

Table 4-1: ARMA 3, 1 Coefficients

Term	Lag	Estimate	Std Error	t Ratio	Prob>|t|
AR1	1	2.0366	0.1462	13.93	<.0001
AR2	2	-1.2531	0.2830	-4.43	<.0001
AR3	3	0.1973	0.1489	1.32	0.1927
MA1	1	1.0000	0.0608	16.45	<.0001
Intercept	0	18.8611	1.6921	11.15	<.0001

From the results of the t-tests it appears that the AR3 variable does not contribute any predictive properties to the model. But an ARMA (2, 1) model has a lower adjusted R^2 and the AIC is also greater, indicating a less predictive model. Thus an ARMA (3, 1) was selected for this forecast.

Predictive Variables

In order to build the simple structural models, I first evaluated the subsets of variables identified in figure 3-1. Each variable was tested using various lags ranging from one to seven, as well as being plotted in an XY plot for evaluation of possible polynomial correlations. This chapter presents the evaluation of each subset first, and then compares the most predictive variables from all subsets.

Economic Indicators

The correlations of the most predictive lagged variables for the economic indicators tested are presented in table 4-1. The XY plots for Real GDP, GDP Deflator, Population, and Real GDP per capita show little if any predictive properties regardless of lags taken. Further, they do not appear to be suitable for fitting a least squares line through them, even using polynomial equations.

Both the first order difference for the population of the US lagged 7 years and the first order difference of the GDP deflator lagged one year showed better predictive properties when fitted using a 2nd order polynomial equation. But the correlation between the change in population in the US and world oil prices is rather weak and fails the logic test. How would a large population increase seven years ago drive prices down this year? The GDP deflator has a very strong correlation. This would be consistent with the inflation rate in one year, having a ripple effect on price changes in following years.

Table 4-2: Economic Correlations

	Price	Real GDP Lag 4	GDP Deflator	Real GDP per Capita Lag 4	Real GDP per Capita Lag 4 (Diff)	GDP Deflator Lag 1
Price	1	0.3450	0.4001	0.3678	0.1578	0.7861
Real GDP Lag 4	0.3450	1	0.9819	0.9970	0.3210	0.4898
GDP Deflator	0.4001	0.9819	1	0.9840	0.2754	0.5361
Real GDP per Capita Lag 4	0.3678	0.9970	0.9840	1	0.3234	0.5363
Real GDP per Capita Lag 4 (Diff)	0.1578	0.3210	0.2754	0.3234	1	0.2195
GDP Deflator Lag 1	0.7861	0.4898	0.5361	0.5363	0.2195	1

Consumption

The correlation between the consumption of the economic sectors and the price of oil all had a negative correlation though the strongest correlation for each sector was found at different lags. In fact, the correlation between the first order difference of both oil consumption to generate electric power and industrial consumption were strongest without any lag. As a result they are not good predictors for crude oil prices. Further, there is a strong correlation between the first order difference of commercial consumption lagged two periods and the first order difference of residential lagged two periods. These factors result in a less predictive variable when combined. And when the price of crude oil is regressed against these variables together the commercial variable does not contribute any significant predictive properties. As a result the most predictive variable for this sub-set of variables is the first order difference of residential consumption lagged two periods with the first order difference of consumption for transportation lagged one period being a close second. The best consumption data is presented in table 4-3.

Table 4-3: Consumption

	Price	Population Diff Lag 7	World Pop Diff	industrial diff	Trans Diff Lag 1	Electric Diff	Commercial Diff lag 2	Residential Diff Lag 2
Price	1	-0.3735	0.3404	-0.4951	-0.5939	-0.6099	-0.4222	-0.6856
Population Diff Lag 7	-0.3735	1	-0.3805	0.1380	0.3267	0.3117	0.3624	0.3976
World Pop Diff	0.3404	-0.3805	1	-0.0954	-0.1850	-0.0657	-0.3743	-0.3234
Industrial Diff	-0.4893	0.1380	-0.0775	1	0.3823	0.3641	0.03728	0.1929
Trans Diff Lag 1	-0.5879	0.3267	-0.1204	0.3860	1	0.4781	0.3301	0.6243
Electric Diff	-0.6098	0.3117	-0.0657	0.3604	0.4648	1	0.1922	0.3365
Commercial Diff lag 2	-0.4222	0.3624	-0.3743	0.03728	0.3448	0.1922	1	0.5618
Residential Diff Lag 2	-0.6856	0.3976	-0.3234	0.1929	0.6268	0.3364	0.5618	1

The subset of variables was evaluated for a possible fit with a polynomial equation. Some of the variables could best be fitted with a second order polynomial equation. But the p-values from t-tests indicated that the variables were beginning to lose their predictive properties. As a result it is not likely that the squares of these variables will be used in a final model. Thus more parsimonious forecast models were pursued rather than a more heavily parameterized version.

Strategic Oil Reserves (SOR)

The correlation between the SOR and price was strongest when only the change in the reserves was considered. Not surprisingly, the total petroleum and the number of days in the SOR have the strongest correlation when the change occurs. The strongest correlation for the percent crude appears to occur when it is lagged two periods. All three of these variables predictive properties can be improved by using a second order polynomial equation. But, in both the Number of days and the percent of crude oil in the SOR this is likely because of an overly influential data point or points. This can be seen in figure 4-1 through 4-3. Further the p-value for the t-tests for the total petroleum indicated that the predictive value for a polynomial equation is beginning to become less reliable.

Table 4-4: U.S. Strategic Oil Reserves

	Price	Total Pet Diff	SOR Days Diff	SOR Diff lag 2
Price	1	0.6911	0.7071	0.6506
Total Pet Diff	0.6888	1	0.7644	0.3441
SOR Days Diff	0.7100	0.7649	1	0.4037
Percent Crude in SOR Diff lag 2	0.6506	0.3441	0.4045	1

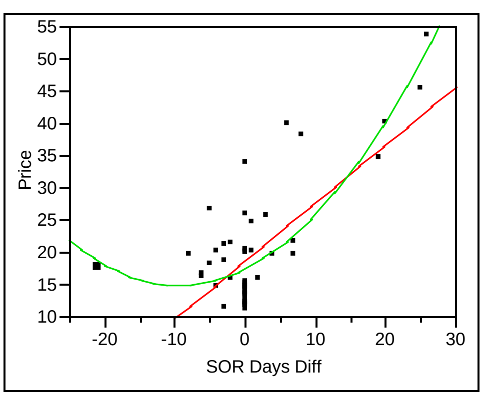

Figure 4-1: Oil Price by SOR Days

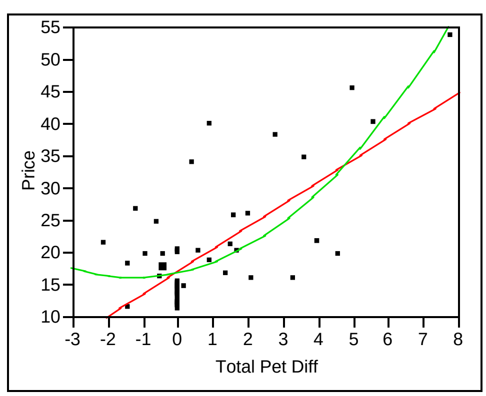

Figure 4-2: Oil Price by Total Petroleum in SOR

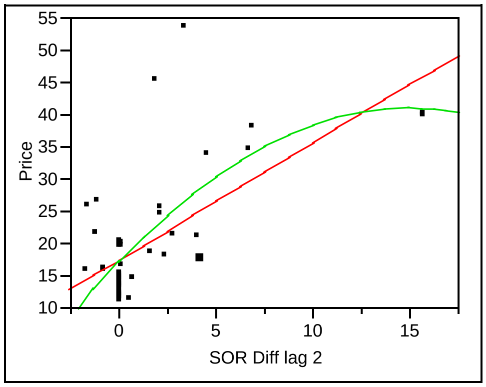

Figure 4-3: Oil Price by Percent Crude in SOR

Global Oil Production

Using oil production as a predictive variable has yielded disappointing results. Up until about 1994, the change in production of oil has had a negative correlation with the price of oil. This is shown in figures 4-4 through 4-6. But in the last several years that relationship seams to have shifted to a positive correlation, as seen in figures 4-7 through 4-9. Likely, this is the result of changing policies in OPEC and other underlying factors. For this reason the correlation coefficients for these variables were not calculated.

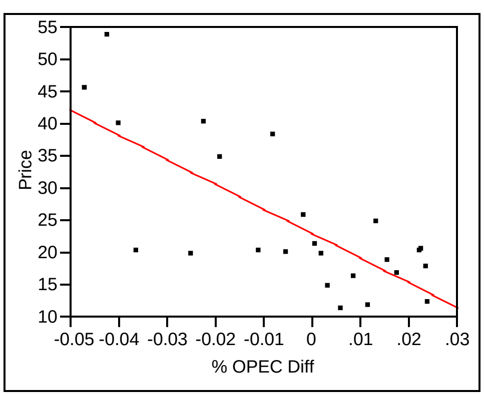

Figure 4-4: Oil Price by Percent OPEC Annual Change

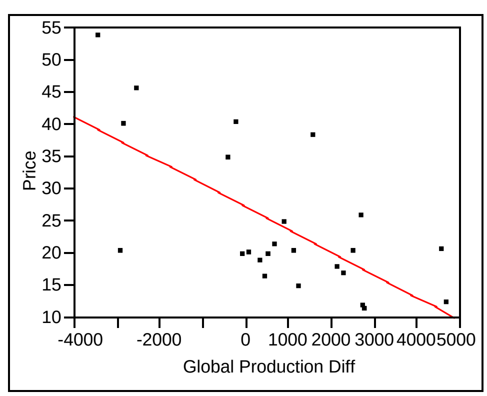

Figure 4-5: Oil Price by Global Production Growth

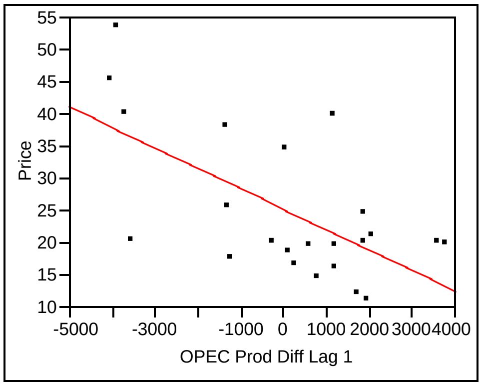

Figure 4-6: Oil Price by OPEC Production Growth

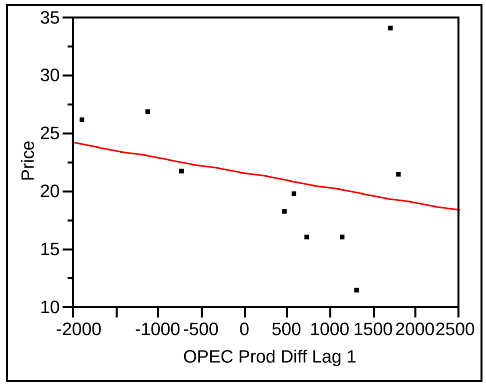

Figure 4-7: Price by Percent OPEC Annual Change

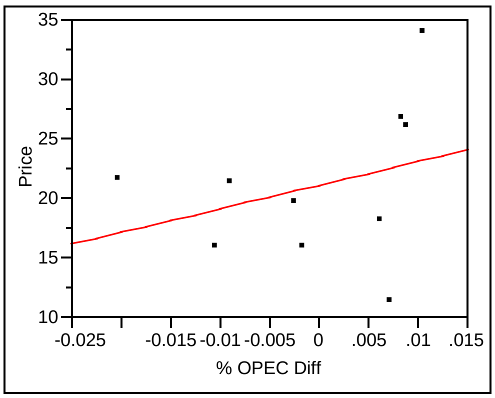

Figure 4-8: Oil Price by Global Production Growth

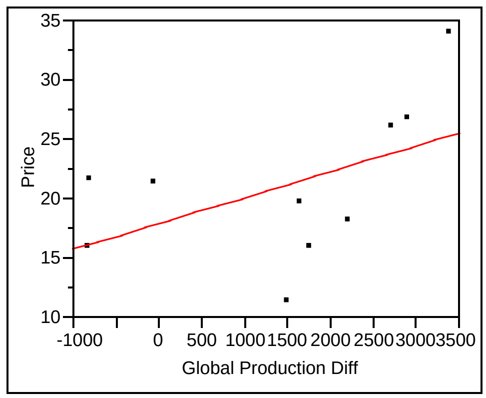

Figure 4-9: Oil Price by OPEC Production Growth

Oil Infrastructure and Exploration

The best correlation in this subset by far is the number of wells drilled, but this variable is not lagged. The reason for this correlation is best explained when the number of wells drilled is a function of the price of oil rather than the price of oil is a function of drilling for oil. This is a classic structural model consideration which has been avoided in this research.

Refinery utilization, like oil production, is rather problematic. Figure 4-10 illustrates the price of oil plotted by refinery utilization from 1970 to 1993. During much of this time OPEC attempted to restrict oil production to increase prices, which explains why lower utilization rates had higher prices. The opposite is true from 1994 to 2004, as shown in figure 4-11. While the p-values for the t-test for the last 11 years indicate a much less predictive variable, it is a good indication that the world's ability to produce oil and oil products may be reaching a supply capacity constraint. Tables 4-4 through 4-6 display the correlation coefficients for all available years, pre-1993 and post-1993 respectively.

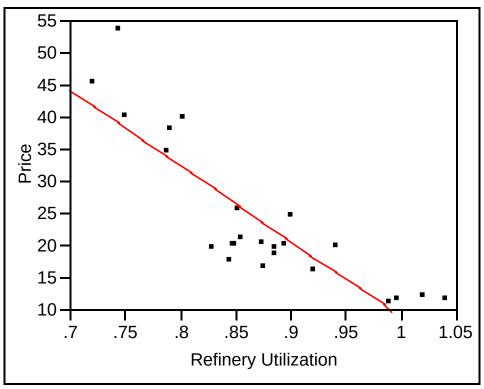

Figure 4-10: Oil Price by Refinery Utilization (pre-1993)

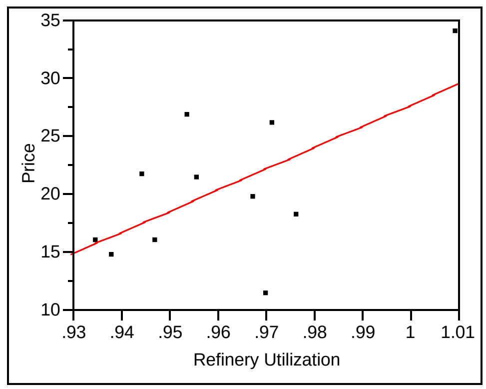

Figure 4-11: Oil Price by Refinery Utilization (Post-1993)

Table 4-5: Infrastructure and Exploration

all Years	Price	Wells Drilled	Refinery Utilization	Global Dist lag 1	World Dist Diff
Price	1	0.7943	-0.7271	0.5347	-0.3618
Wells Drilled	0.7932	1	-0.8061	0.3630	-0.2724
Refinery Utilization	-0.7271	-0.8061	1	-0.3685	0.3414
Global Dist lag 1	0.5347	0.3630	-0.3685	1	-0.6573
World Dist Diff	-0.3618	-0.2724	0.3414	-0.6573	1

Table 4-6: Pre-1993 Infrastructure and Exploration

Pre 1993	Price	Wells Drilled	Refinery Utilization	Global Dist lag 1	World Dist Diff
Price	1	0.8657	-0.8568	0.6681	-0.3865
Wells Drilled	0.8657	1	-0.8338	0.5921	-0.3189
Refinery Utilization	-0.8568	-0.8338	1	-0.8341	0.4949
Global Dist lag 1	0.6681	0.5921	-0.8341	1	-0.7098
World Dist Diff	-0.3865	-0.3189	0.4949	-0.7098	1

Table 4-7: Post-1993 Infrastructure and Exploration

Post 1993	Price	Wells Drilled	Refinery Utilization	Global Dist lag 1	World Dist Diff
Price	1	0.6923	0.6036	0.7326	-0.3914
Wells Drilled	0.6923	1	0.7661	0.6273	-0.4259
Refinery Utilization	0.6036	0.7661	1	0.2854	-0.0920
Global Dist lag 1	0.7326	0.6273	0.2854	1	-0.2565
World Dist Diff	-0.3914	-0.4259	-0.0920	-0.2565	1

Current Events and Time

The price of oil has a strong correlation coefficient with all the variables tested. The variable for supply constraint was added because the correlation between a restrictive OPEC pricing policy and the binomial variable for war is rather large. In essence it is a binomial variable with a 1 representing an event restricting the supply of crude oil. Further evaluation of the constant oil policy indicates that it is very predictive before 1973, but in the years that follow it has very poor correlation with the price of oil.

Table 4-8: Current Events

	Price	Const oil Policy	OPEC Restrict	War	Supply Constraint
Price	1	-0.5088	0.6790	0.6675	0.8345
Const oil Policy	-0.5088	1	-0.3520	-0.4865	-0.3520
OPEC Restrict	0.6790	-0.3520	1	0.5039	0.6028
War	0.6675	-0.4865	0.5039	1	0.7235
Supply Capacity Constraint	0.8345	-0.3520	0.6028	0.7235	1

Time

Like the binomial variable for constant oil price, the year has very poor correlation with the price of oil after 1973. As a result, it is not considered further.

Table 4-9: Time

	Price	Year
Price	1	0.3932
Year	0.3932	1

Best Predictors

The nine variables with the best correlation coefficient are displayed in table 4-10. The top three predictors all have a correlation coefficient of greater than 0.8 while the variable with the least predictive potential still has a correlation coefficient of 0.65.

Table 4-10: Best Predictors

	Price	GDP Deflator	Residential Lag 2	SOR lag 2	OPEC Restriction	war	Supply Capacity Constraint	ARMA 3, 1	Wells Drilled	Wells Drilled Lag 1
Price	1	0.8336	-0.6856	0.6506	0.6790	0.6675	0.8153	0.8194	0.7943	0.6594
GDP Deflator	0.8336	1	-0.7083	0.4840	0.5939	0.5369	0.5400	0.8342	0.6260	0.5626
Residential Lag 2	-0.6856	-0.7083	1	-0.2960	-0.4647	-0.3587	-0.4372	-0.6409	-0.4831	-0.3830
SOR lag 2	0.6506	0.4840	-0.2960	1	0.5772	0.5354	0.5458	0.5793	0.5991	0.5941
OPEC Restriction	0.6790	0.5939	-0.4647	0.5772	1	0.5039	0.5179	0.6971	0.6521	0.5736
War	0.6675	0.5369	-0.3587	0.5354	0.5039	1	0.6144	0.5965	0.4511	0.4950
Supply Capacity Constraint	0.8153	0.5400	-0.4372	0.5458	0.5179	0.6144	1	0.5593	0.6014	0.4890
ARMA 3, 1	0.8194	0.8342	-0.6409	0.5793	0.6971	0.5965	0.5593	1	0.8288	0.8620
Wells Drilled	0.7943	0.6260	-0.4831	0.5991	0.6521	0.4511	0.6014	0.8288	1	0.8711
Wells Drilled Lag 1	0.6594	0.5626	-0.3830	0.5941	0.5736	0.4950	0.4890	0.8620	0.8711	1

Structural Forecasting Models

Two structural models were built for this thesis, one using an ARMA forecast and one using the number of wells drilled in the US. Both of these variables have good correlation coefficients with the price of oil and each other. The ARMA model performs better, but the model incorporating the number of wells drilled has other advantages.

ARMA Structural Model

A regression model using the ARMA (3, 1) described earlier in this chapter, a variable representing a capacity constraint restriction, and the first order difference of the GDP Deflator was built. Only data after 1973 was considered for this model because prior to that time the variance in the price of oil was very low, and displayed a strong negative trend. In 1973, OPEC managed to effectively manipulate the price of oil for the first time, and since that time the oil market has been very volatile (Cremer, 1991). Figure 3-2 displays the real price of oil from 1950 to 2004. Attempts to forecast using this data resulted in better R^2 values but were less effective at forecasting over the hold-out set.

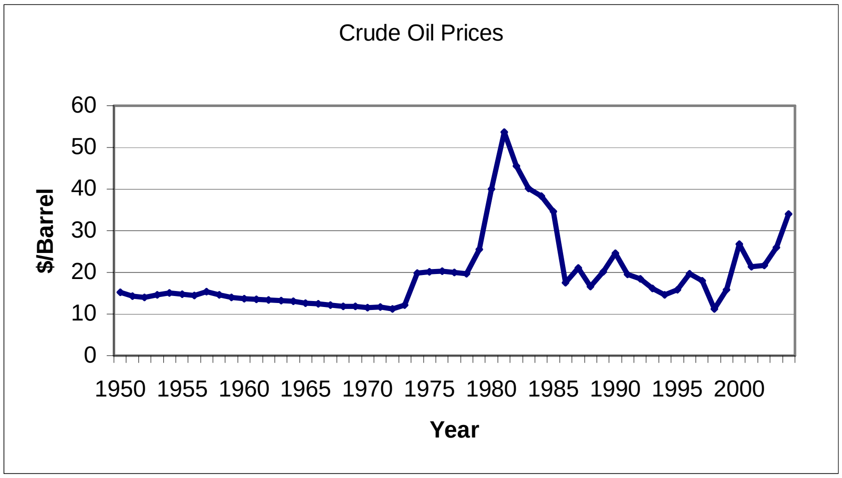

Figure 4-12: Crude Oil Prices 1950 – 2004

The model developed is expressed as $F_t = \theta + \beta\,$(ARMA 3, 1)$\,+ \beta\,$(GDP Deflator)$\,+ \beta\,$(Restricted Supply). Table 4-11 displays the coefficients as well as the standard error and t-test results.

Table 4-11: ARMA Structural Model Coefficients

Term		Estimate	Std Error	t Ratio	p-value
Intercept		6.7708	2.5134	2.6900	0.0144
GDP Deflator		3.6694	0.6957	5.2700	<.0001
ARMA 3, 1		0.1905	0.0996	1.9100	0.0709
Supply Constraint		15.6108	2.3360	6.6800	<.0001

The adjusted R^2 and f-test are presented in table 4- 12. Given the results of the t test and f-test coupled with extremely high R^2, we can conclude that this model is capable of predicting oil prices.

Table 4-12: ARMA Structural Model Results

R^2	0.954615
Adjusted R^2	0.946606
F Ratio	119.1923
p-value	<0.0001
Observations	21

The GDP Deflator provides feedback on the rate of economic growth. Higher economic growth rates translate to higher demand for petroleum, and petroleum-based products. It can also be argued that increasing petroleum prices will cause an increase in prices throughout a modern economy because it is systemic to production of virtually all good and services. In that way it also gives an indication of the supply of oil with tighter supplies bringing higher prices. The price path for crude oil is like a pendulum, moving from disequilibrium to equilibrium and eventually over-correcting to another state of disequilibrium. The ARMA 3, 1 provides the basic price path moves through these cycles, seeking a steady state. Finally, the supply constraint identifies times where the production and distribution of crude oil is constrained for some reason. In 1980, it was OPEC cutting production dramatically in an effort to raise the price of oil, coupled with a war in the region. The more recent constraint is due to higher marginal cost for OPEC production and the high refinery capacity utilization rates.

The model was tested against the three major assumptions of regression: normality, independence, and constant variance of the residuals. The results were consistent with the assumptions and are located in Appendix 1.

Wells Drilled Structural Model

Because the correlation coefficient between the ARMA 3,1 model and the number of wells drilled in the US lagged one period is high, a model was built substituting those variables. Only data after 1973 was considered. The forecast model is expressed as $F_t = \theta + \beta\,(\text{US Wells Drilled}) + \beta\,(\text{GDP Deflator}) + \beta\,(\text{Restricted Supply})$. Table 4-13 displays the coefficients as well as the standard error and t-test results.

Table 4-13: Wells Drilled Structural Coefficients

Term		Estimate	Std Error	t Ratio	p-value
Intercept		5.3120	3.5169	1.51	0.1504
DFLTR Diff		4.1880	0.7930	5.28	<0.0001
Supply Constraint		15.3603	2.6288	5.84	<0.0001
Wells Drilled Lag 1		0.0000214	0.000012	1.72	0.1039

While the t-test results for the number of wells drilled lagged greater than the 0.10 cut-off described in chapter 3, it has been accepted. The results were very close to the threshold and the model much more predictive with this variable. The adjusted R^2 and f-test are presented in table 4-14. This model is nearly as good as the ARMA structural model described earlier, but the p-values for the intercept and wells drilled do not indicate as strong a model. But it has other advantages and the coefficients for both models are very similar for both models. As a result, this is likely a viable model as well.

Table 4-14: Wells Drilled Structural Model Results

R^2	0.9514
Adjusted R^2	0.9422
F Ratio	104.3179
p-value	<0.0001
Observations	20

The number of wells drilled in the US, like the ARMA (3, 1) model provides a basic price path, but it also provides some insight as to why. As the price of oil increases the number of wells also increases. Eventually the growth in production exceeds the growth in demand and oil prices fall. When prices eventually reach a trough, production growth no longer keeps up with demand growth and the cycle begins again.

The three assumptions for regression were tested and this model passed these tests as well. The results are presented in Appendix 1.

Forecast model results

A forecast of the difference of the GDP deflator from 1994 to 2004 was used to forecast oil prices from 1994 to 2004 (Smirnoff, 2006). There are several GDP deflator forecasts available to forecast for the years after 2004 including one from the EIA or from commercial sources like Global Insight. To forecast beyond 2004, the EIA forecasted GDP chained-type price index from the 2006 AEO early release will be used.

The supply capacity constraint variable for the years 2000 through 2003 used a 0.5 and a 1 in 2004. OPEC re-achieved its previous record production rates (1976) in 2000. This means increases in production after that will require a much greater investment than the years from 1976 to 1999. As seen in figure 4-1, OPEC production dropped from 1979 to the mid 1980s. After that time OPEC production rates have increased steadily. OPEC production rates reasonably could have been forecasted to reach record levels around 2000.

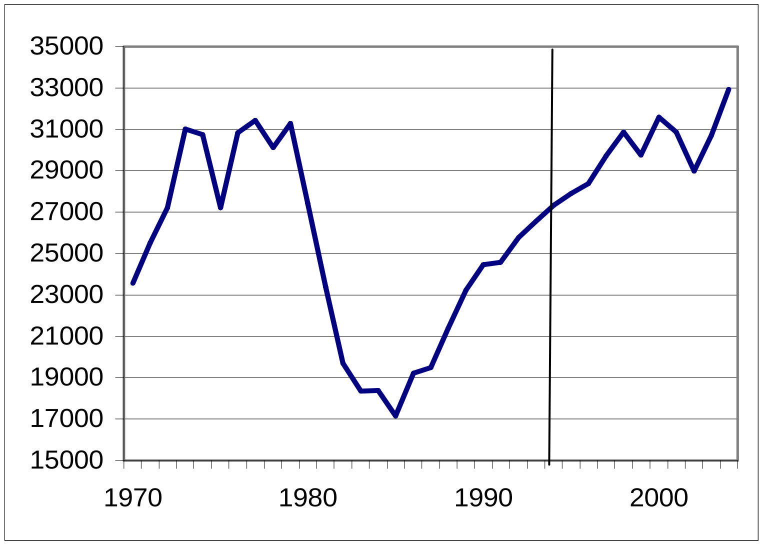

Figure 4-13: OPEC Production

In 2004 the global refinery utilization rate exceeded 100 percent. This was only the third time this has happened since 1970. The first two occurrences happened during the 1970s, when the correlation between oil prices and refinery utilization had a negative correlation. Figure 4-14 displays the global refinery utilization rate. While the utilization dipped in the late 1990s and early in 2000s, the utilization seems to approach the logical limit of 1. That is, as the utilization approaches 1, its approach slows. Because global utilization of refineries can be sustained above 100 percent this makes sense. Therefore refinery utilization could have been forecasted to very near or exceeding 100 percent in 2004.

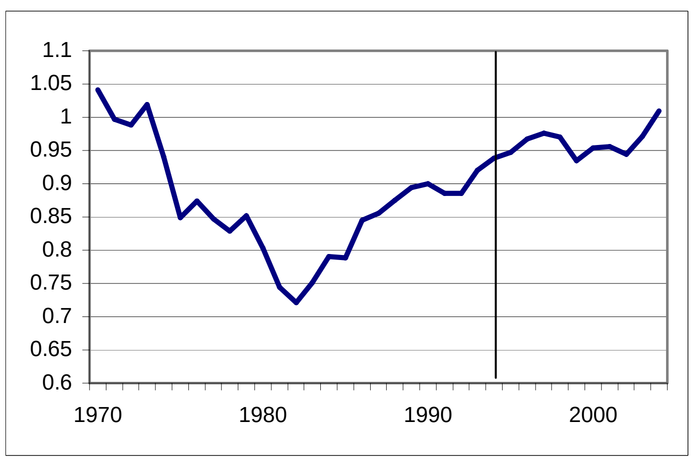

Figure 4-14: Global Refinery Utilization

Forecast Performance

The models were then used to forecast the price of oil from 1994 to 2004 and the results compared to the known 1994 to 2004 prices as stated earlier in the chapter. To determine the accuracy of the models the following error measurements were calculated: MSE, MAPE, ME and MPE. For the purpose of this study all five measurements will be calculated. But when comparing forecast, the measurements do not always agree, so the forecast with the best MAPE and MSE will be considered superior.

ARMA Model Forecast

Table 4-15 displays the price of crude oil, the independent variables and the forecasted price of crude oil using the reduced form model from 1994 to 2004 as well as the error measurements for each year.

Table 4-15: ARMA Structural Model Forecast

Year	Price	GDP Deflator Difference	ARMA	Supply Constraint	Forecast	Error	ABS Error	PE	APE	error sq
1994	14.61	2.0	14.9218	0.0000	16.9522	-2.3422	2.3422	-16.0315	16.0315	5.4859
1995	15.87	2.2	14.2040	0.0000	17.5493	-1.6793	1.6793	-10.5819	10.5819	2.8202
1996	19.67	2.8	13.7718	0.0000	19.6686	0.0014	0.0014	0.0069	0.0069	0.0000
1997	18.06	2.6	13.5548	0.0000	18.8934	-0.8334	0.8334	-4.6148	4.6148	0.6946
1998	11.27	2.2	13.5127	0.0000	17.4176	-6.1476	6.1476	-54.5488	54.5488	37.7936
1999	15.9	2.0	13.6136	0.0000	16.7030	-0.8030	0.8030	-5.0503	5.0503	0.6448
2000	26.72	2.2	13.8291	0.5000	25.2833	1.4367	1.4367	5.3768	5.3768	2.0640
2001	21.33	2.8	14.1332	0.5000	27.5429	-6.2129	6.2129	-29.1275	29.1275	38.6001
2002	21.63	3.0	14.5023	0.5000	28.3471	-6.7171	6.7171	-31.0545	31.0545	45.1193
2003	26	2.1	14.9156	0.5000	25.1234	0.8766	0.8766	3.3717	3.3717	0.7685
2004	33.97	2.1	15.3548	1.0000	33.0124	0.9576	0.9576	2.8189	2.8189	0.9169

Wells Drilled Model Forecast

Table 4-16 displays the results of the regression model over the holdout data set.

Table 4-16: Wells Structural Model Forecast

Year	Price	GDP Deflator Difference	Wells Drilled Lag 1	Supply Constraint	Forecast	Error	ABS Error	PE	APE	error sq
1994	14.61	2.0	135118	0	16.5795	-1.9695	1.9695	-13.4807	13.4807	3.8790
1995	15.87	2.2	124809	0	17.1965	-1.3265	1.3265	-8.3586	8.3586	1.7596
1996	19.67	2.8	117832	0	19.5600	0.1100	0.1100	0.5592	0.5592	0.0121
1997	18.06	2.6	129045	0	18.9624	-0.9024	0.9024	-4.9965	4.9965	0.8143
1998	11.27	2.2	156661	0	17.8781	-6.6081	6.6081	-58.6348	58.6348	43.6676
1999	15.9	2.0	143454	0	16.7579	-0.8579	0.8579	-5.3957	5.3957	0.7360
2000	26.72	2.2	99410	0.5	24.3331	2.3869	2.3869	8.9329	8.9329	5.6972
2001	21.33	2.8	141392	0.5	27.7443	-6.4143	6.4143	-30.0719	30.0719	41.1437
2002	21.63	3.0	187616	0.5	29.5711	-7.9411	7.9411	-36.7135	36.7135	63.0616
2003	26	2.1	138310	0.5	24.7468	1.2532	1.2532	4.8201	4.8201	1.5706
2004	33.97	2.1	177074	1	33.2565	0.7135	0.7135	2.1004	2.1004	0.5091

Annual Energy Outlook Forecast

The 1993 EIA AEO forecast is presented in table 4-17. Additionally the EIA forecasts from 1994 and earlier were compared to the actual price of oil by plotting the forecast and by calculating the first error measurements for the first 5 years of the forecast. Figure 4-15 displays the actual price of crude oil and the AEO forecast prices for the 1991 through 1994 forecasts. To simplify the diagram, the x-axis begins in 1994. Not surprisingly, the forecasts get more accurate as the time horizon gets nearer. But when the 1998 to 2001 forecast are evaluated, the forecasts seem to change the starting point and adjust to some predetermined future price. Figure 4-16 shows this data. Note the forecasted price for each of these forecasts converge around $25 in 2006 or 2007. Given that the price of crude oil will likely exceed $40/barrel in 2005 and the 2006 AEO Forecast exceeds $45/barrel it is unlikely that these forecasts will ever achieve any notable accuracy. These trends can also be seen in the performance of the first 5 years for each forecast from 1991 to 2000. Figure 4-17 shows the ME, MPE, MAPE, and MSE of the first 5 years for each forecast* from 1991 to 2000.

Table 4-17: 1993 AEO Price Forecast

Year	Price	Forecast	Error	Abs Error	PE	APE	E^2
1994	14.61	20.77	-6.1627	6.1627	-42.1817	42.1817	37.9794
1995	15.87	21.77	-5.9021	5.9021	-37.1904	37.1904	34.8349
1996	19.67	22.64	-2.9705	2.9705	-15.1015	15.1015	8.8236
1997	18.06	23.54	-5.4761	5.4761	-30.3216	30.3216	29.9874
1998	11.27	24.52	-13.2471	13.2471	-117.5433	117.5433	175.4863
1999	15.90	25.69	-9.7872	9.7872	-61.5548	61.5548	95.7897
2000	26.72	27.30	-0.5812	0.5812	-2.1752	2.1752	0.3378
2001	21.33	28.92	-7.5924	7.5924	-35.5949	35.5949	57.6445
2002	21.63	28.32	-6.6856	6.6856	-30.9087	30.9087	44.6966
2003	26.00	29.54	-3.5403	3.5403	-13.6165	13.6165	12.5337
2004	33.97	30.64	3.3306	3.3306	9.8046	9.8046	11.0931

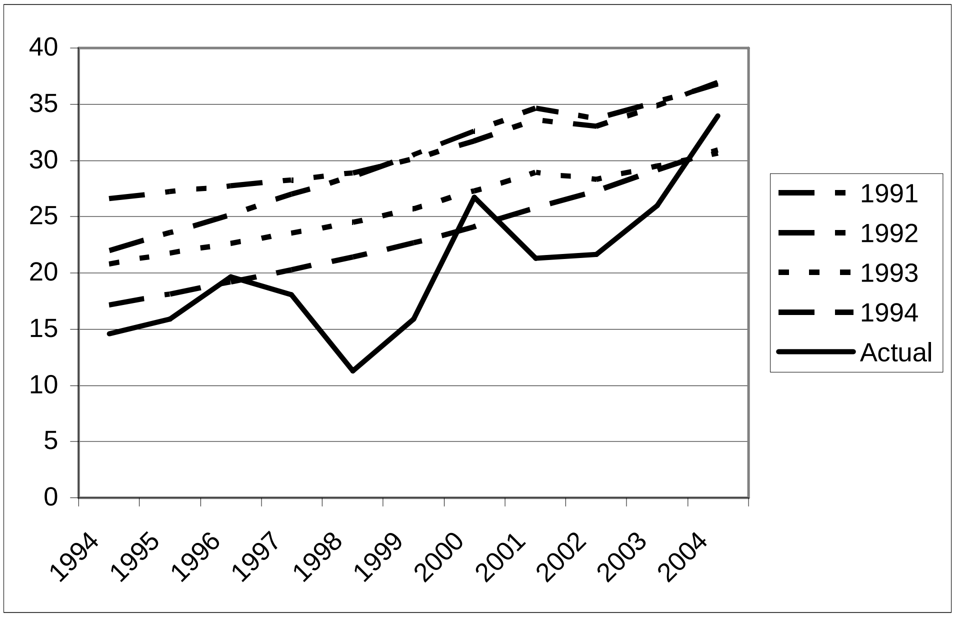

Figure 4-15: Forecast v. Actual Price of Crude 1994 to 2004

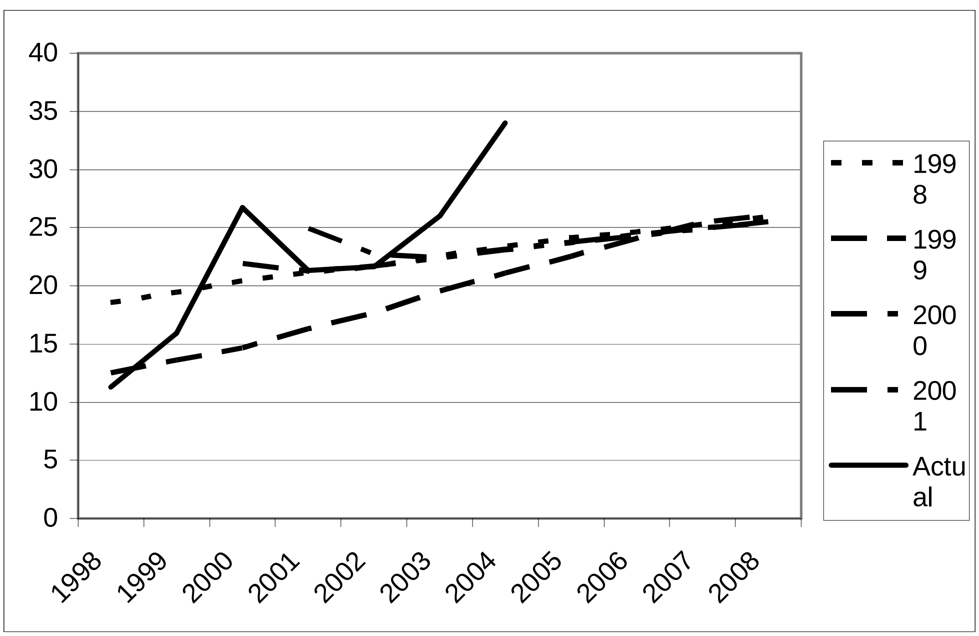

Figure 4-16: Forecast v. Oil Price 1998 to 2008

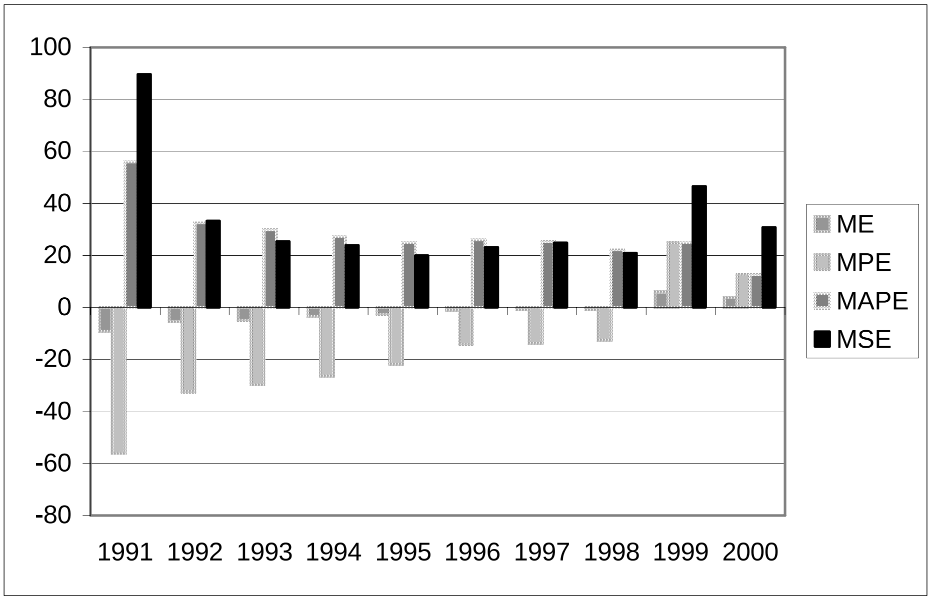

Figure 4-17: Five Year Forecast Error 1991 to 2000

1995 Dermot Gately Model.

The global GDP, has reported by the EIA, has grown by a total of 40 percent since 1994. During the same period, OPEC production has only grown by 17 percent. Given this output growth path, Gately defined three options: optimal, reference, and pessimistic. Figure 4-6 illustrates the actual price path of oil and the three forecasted trends in 2000 dollars per barrel. The difference between three options is in the growth rate in Non-OPEC output. The pessimistic option assumes that the Non-OPEC output will grow much faster than the reference case; with the optimal case the non-OPEC growth will be much slower than the reference case.

The actual growth from 1994 for Global GDP, OPEC production Non-OPEC production and Global Production is shown in table 4-18. Although world oil production has already exceeded the 2010 forecasted rates for this scenario, it seems plausible that in 2010 the price of crude oil could be between $34 and $51 per barrel. Gately's forecasted OPEC production growth is consistent with the reference and optimal cases of the scenario in which OPEC increases production exactly as fast as world income growth and the price is close to the optimal price path of that scenario as well. Where this scenario falls apart is in the income growth and non-OPEC production growth. It is plausible that OPEC intended to grow production as fast as the growth rate in the GDP, but miss judged growth in the global economy. This supports a 2010 price of around $51 per barrel.

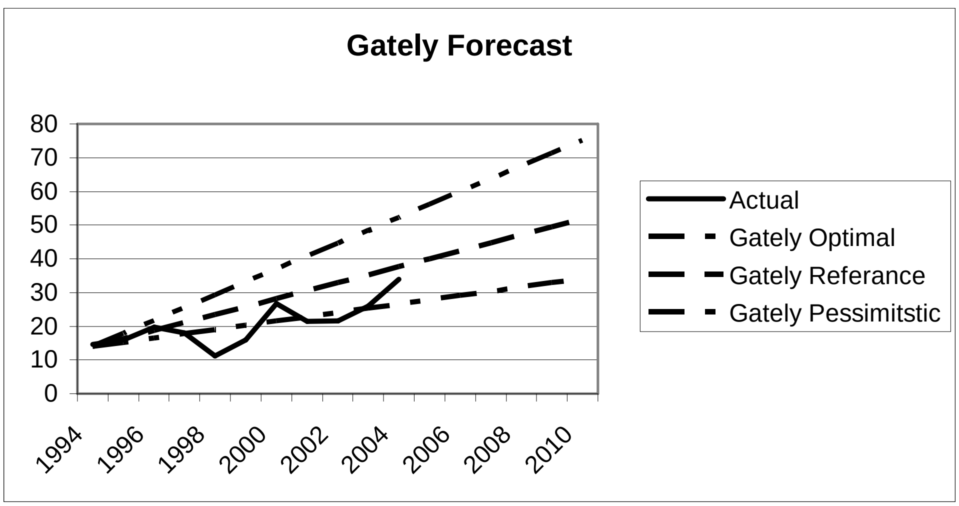

Figure 4-6: Gately Forecast

Table 4-18: Cumulative GDP and Oil Production Growth

Year	Cumulative GDP Change	Cumulative Percent GDP Change	Cumulative OPEC Output Change	Cumulative Percnet OPEC Change	Cumulative Percent OPEC/ Cumulative Percnet GDP	Cumulative Non-OPEC Change	Cumulative Non-OPEC Percent Change	Cumulative Percent Non-OPEC/ Cumulative Percent GDP	Cumulative Global Percent Change / Cumulative GDP percent change
1995	325.5	0.0440	589.62	0.0211	0.4801	1169.88	1.1070	0.6269	1.1070
1996	744.7	0.0953	1070.06	0.0377	0.3956	2336.65	0.9584	0.5628	0.9584
1997	1232.1	0.1484	2403.98	0.0809	0.5451	3222.84	1.0336	0.4885	1.0336
1998	1674.8	0.1915	3556.11	0.1152	0.6015	3573.66	1.0180	0.4165	1.0180
1999	2196.2	0.2370	2441.94	0.0820	0.3462	3861.80	0.7076	0.3613	0.7076
2000	2744.8	0.2796	4256.89	0.1348	0.4821	4953.26	0.8656	0.3835	0.8656
2001	3055.8	0.3017	3549.72	0.1150	0.3811	5616.09	0.7783	0.3972	0.7783
2002	3397.4	0.3245	1672.36	0.0577	0.1777	6698.77	0.6083	0.4306	0.6083
2003	3899	0.3554	3402.72	0.1107	0.3116	7683.29	0.7535	0.4419	0.7535
2004	4662.1	0.3973	5600.44	0.1701	0.4282	8888.24	0.8744	0.4463	0.8744

Because Gately did not provide a year by year forecast of oil prices for any of the scenarios outlined, his forecast is not presented. His forecast does support the reduced form and regression models though.

Consensus Forecast

Because the AEO forecasted is more focused on the quantity of oil demanded and the effects of various policies on availability of oil supplies its price has not been historically accurate. Further, it offers little complementary properties to the reduce form models created for this thesis, so it is not used in the in the consensus forecast. While the

Gately models offer some potential, year by year forecasts are not available. Therefore only reduced form forecasts will be used to build a consensus model.

The weights for the two structural models were calculated and are presented in table 4-20. Because these forecasts were so similar the weights are nearly the same. When the consensus forecast was computed the resulting MAPE and MSE over the holdout set was inferior to that of the ARMA alone. If suitable forecast had been available this forecast may have provided better forecast performance. The consensus forecast is presented in table 4-19.

Table 4-19: Consensus Weights

	MAE	1/MAE	Weight
ARMA	1.8372	0.5443	0.5059
Wells	1.8813	0.5316	0.4941

Table 4-20: Consensus Forecast

Year	Price	Reduced Form	Regression	Consensus	APE	E^2
1994	14.61	16.7828	16.2804	16.53459	2.5719	2.4259
1995	15.87	16.2430	16.5799	16.40945	12.3166	0.0001
1996	19.67	16.8703	17.1969	17.03163	7.3197	18.6901
1997	18.06	19.1604	19.5604	19.35801	1.5861	11.4915
1998	11.27	18.3114	18.9627	18.6332	3.1739	2.5288
1999	15.9	16.7063	17.8786	17.28549	53.3762	3.1252
2000	26.72	15.9327	16.7583	16.34061	2.7711	5.3139
2001	21.33	24.1774	24.3334	24.25449	9.2272	19.4576
2002	21.63	26.6422	27.7447	27.18692	27.4586	4.1478
2003	26	27.5273	29.5716	28.53735	31.9341	1.6465
2004	33.97	24.0364	24.7471	24.38755	6.2017	1.8275

The error measurements for all the forecast are presented in table 4-21. Note that the structural models created in this research outperform the others. If year by year figures had been available for the Gately 1995 model it likely would have produce error measurements similar to the structural models. Complete year by year forecast using the structural models for 2006 through 2030 are presented in Appendix 2.

Table 4-21: Forecast Performance

Model	ME	MAE	MPE	MAPE	MSE
ARMA Structural Model	-1.9512	2.5462	-12.6758	14.7803	12.2643
Wells Structural Model	-1.8101	2.5538	-11.8548	14.5893	13.5747
Consensus Forecast	-1.4330	2.4286	-9.9371	13.5499	11.2305
AEO 1993	5.9342	5.9342	-34.2167	35.9994	46.2916
ARMA 3, 1	6.2469	6.7114	24.5585	28.5647	73.3072

V. CONCLUSION

Since 1973 oil prices have been very volatile. This has given way to a great deal of speculation regarding the future availability of oil, and what price we will pay in the future. It has also created a challenge for business leaders, politicians and even military leaders as they plan for the future. The models provided in this paper offers a dramatic improvement in forecast accuracy over any forecast readily available to the DOD. This should provide DOD leadership with a more accurate prediction of the future and aid with acquisitions, budgeting and hedging strategic fuel supplies.

This chapter is outlined as follows: first the investigative questions and research question will be reviewed, along with the results of those questions, followed by an exploration of possible areas to further this research.

What forecasts have historically been most accurate at predicting fuel prices?

Since 1973 oil price forecasts have not performed well. While the EIA forecasts have not been centered on forecasting oil prices, it is a critical component of their forecasts. When the error of the first 5 years of these forecast are evaluated, one quickly becomes aware of the difficulty the world has faced since 1973. These forecast have been most accurate when prices approach a trough in prices, and generally do not accurately trend future prices.

Other oil price forecasts have been made, but these most often are produced by private corporations using proprietary data. Further, a year by year forecasted price is very difficult to find. This makes it very difficult to compare the relative accuracy of these forecasts.

What variables can be used in a reduced form forecast to improve forecast reliability?

By evaluating various variables, this research was able to identify several variables that had good correlation coefficients. Unfortunately, not all these variables were useful in a structural model. Some of the variables evaluated may become very useful in the future, but because the underlying structure of the market has shifted these variables would be counterproductive. Perhaps the best example of this is global refinery utilization.

The variables representing oil consumption by sector is very interesting. It seems to suggest that the long term elasticity of demand of residential and commercial use is greater than transportation or industrial sectors.

The GDP Deflators impact on the price of oil is also interesting. The fact that the change in the deflator is lagged one year has the largest correlation coefficient indicates that last year's economic growth influences this years price. This is consistent with a demand shift.

The most significant finding is the supply capacity constraint. This could be considered as evidence that Saudi Arabia's reserves are running short or showing signs of fatigue, there is more evidence that it is the result slowing global production, particularly non-OPEC nations or because the infrastructure to extract, ship, refine and distribute oil is nearing full capacity. OPEC production since 1993 has increased at a rate of 1.7 percent per annum. Further, since 2000 OPEC has averaged 1.6 percent per annum. When considered in light of Gately's 2003 paper, it is likely that OPEC will continue to grow at about this rate, through design or disaster. This could prove to be a major challenge to the EIA assumption that OPEC will begin to produce large amounts of oil over that next several years.

<u>How can the most accurate forecast be combined into a consensus forecast?</u>

The lack of year by year forecasts greatly hinders the construction of a consensus Forecast. This is very unfortunate because it limits the number of assumptions considered in the consensus forecast built in this research. If reasonably accurate year by year forecast can be found a more robust model can be built, but as it stand now the consensus model built in this research is limited.

<u>Will a parsimonious and theoretically simple model out perform more heavily parameterized models?</u>

The structural models developed in this research offer significantly better performance than the EIA forecasts, and are similar to the Gately forecasts that are much more complex. While each of these models has unique challenges, they do outperform other models.

<u>How can the USAF better predict long-term fuel prices to enhance the transformation of the forces to face modern threats, improve financial planning and improve logistics planning?</u>

The models created in this research are extremely tractable and offer accurate forecast. They also rely on data that is available from the Department of Energy or other easily obtainable sources. The structural model built using an ARMA model proved to be the most accurate forecast, but it relies on an ARMA model. This adds to the complexity of the model. On the other hand the model using the number of wells drilled lagged one year was nearly as accurate, and has the advantage that the forecast can be used to predict the number of wells drilled in the same year. This prediction can then become an input for the next year's forecasted oil price. While the forecasted price cannot be the sole input to prediction of wells drilled, it offers a great deal of potential. The EIA does not provide a forecast of the number of wells drilled, and if it did it would be based on the forecasted world oil price. This means that before this model can fully be developed, a forecast of the number of wells drilled will need to be developed.

Areas for Continued Research

The number of wells drilled in the US is more than just a variable to forecast the price of oil. It is also a barometer of supply infrastructure development, and can provide insight into the elasticity of supply. As a result, this is an important area for future research.

But US wells drilled are not the only infrastructure research that needs to be accomplished. The ability to move oil from the well to market is a very important variable in the price of oil. As such, the capacity to load and unload oil from tankers and the volume of those tankers could be a very important indicator of oil prices. This parallels the need for further research into oil refinery capacity, though enough data for that research may not be available for a few years.

The insights gleaned from the models built by Gately all provide some interesting insight into the world oil markets. His 1995 elasticity model's prediction of oil prices given an OPEC production growth rate of half as fast as world income growth are consistent with what has actually happened. The error in the early years is due to a much higher non-OPEC production that caused global production growth to exceed world income growth. Further, the actual production growth rate for OPEC is very near the levels he predicted in 2001, 2 percent. But a more accurate model may be to model global production given OPEC's proven growth.

APPENDIX A

Test Conducted

The residuals for the initial data set for both structural models were tested for Normality, independence and Homoscedasticity. Normality was tested using the Shapiro-Wilk goodness of fit test. Independence was tested by calculating the Durban-Watson test statistic, and a visual inspection for any obvious problems. Homoscedasticity or constant variance was tested with the Breasche-Pagan test statistic.

ARMA Structural Model

The test results are presented in table A1-1, Figures A1-1 and A1-2 display the residuals by row and price respectively.

Table A-1: ARMA Structural Model Test Results

Test	Test Statistic	p-value
Shapiro-Wilk	0.9642	0.6297
Durban-Watson	3.0646	0.9874
Breasche-Pagan	000000	0.0050

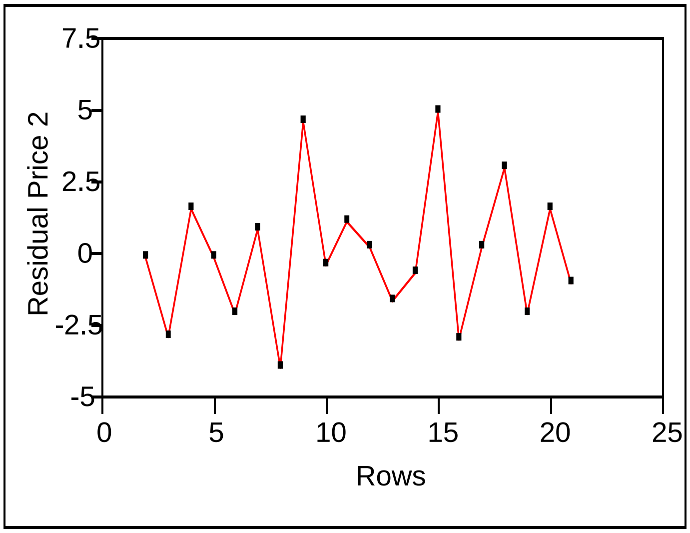

Figure A-1: ARMA Structural Model Residuals by Row

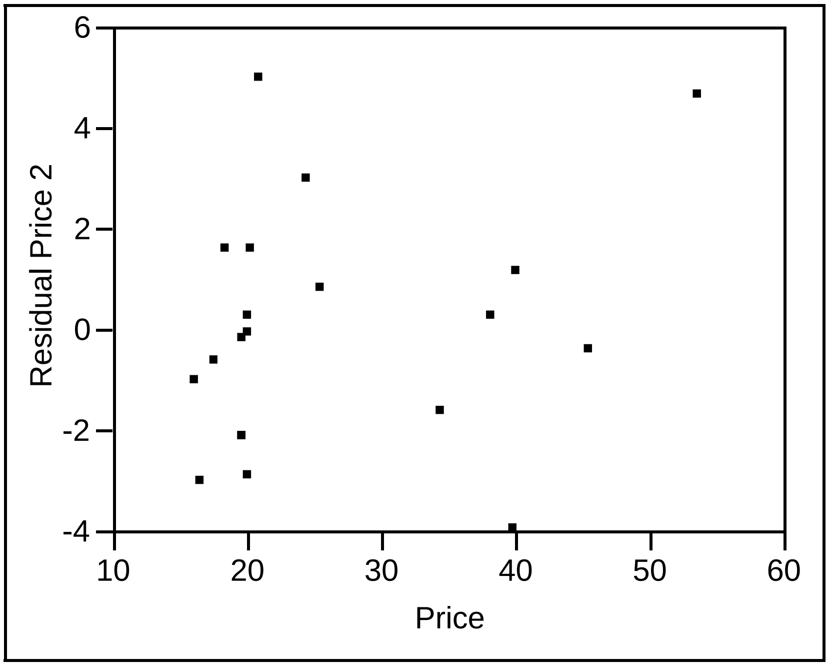

Figure A-2: ARMA Structural Model Price by Residuals

<u>Wells Drilled Structural Model</u>

The results of the test on the residuals from the structural model using the number of well drilled in the US are presented in Table A1-2, and Figures A1-3 and A1-4 are the residuals plotted by row and price respectively.

Table A-2: Wells Drilled Structural Model Test Results

Test	Test Statistic	p-value
Shapiro-Wilk	0.9706	0.7033
Durban-Watson	2.0891	0.3931
Breasche-Pagan		0.1070

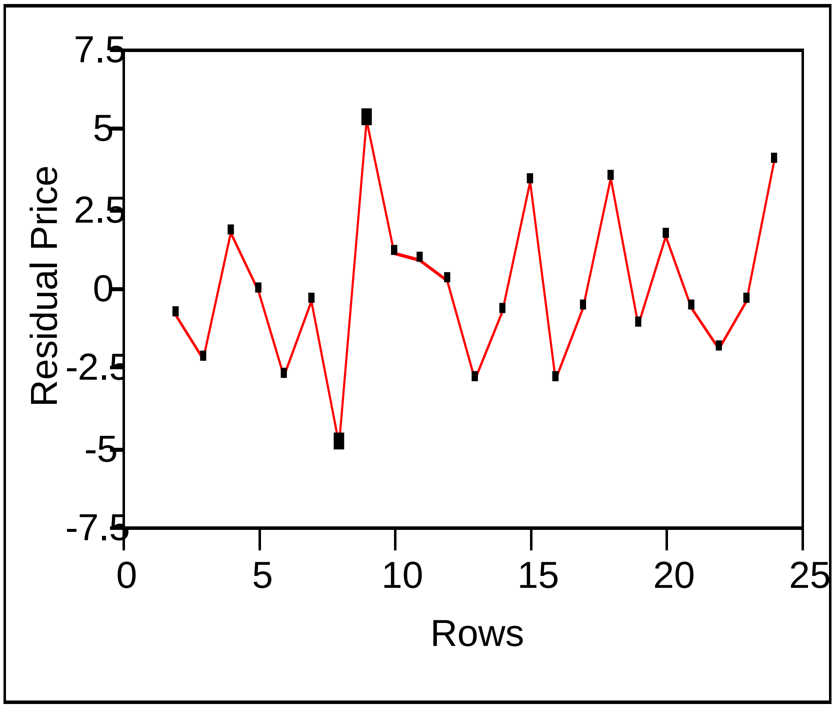

Figure A-3: Wells Drilled Structural Model Residuals by Row

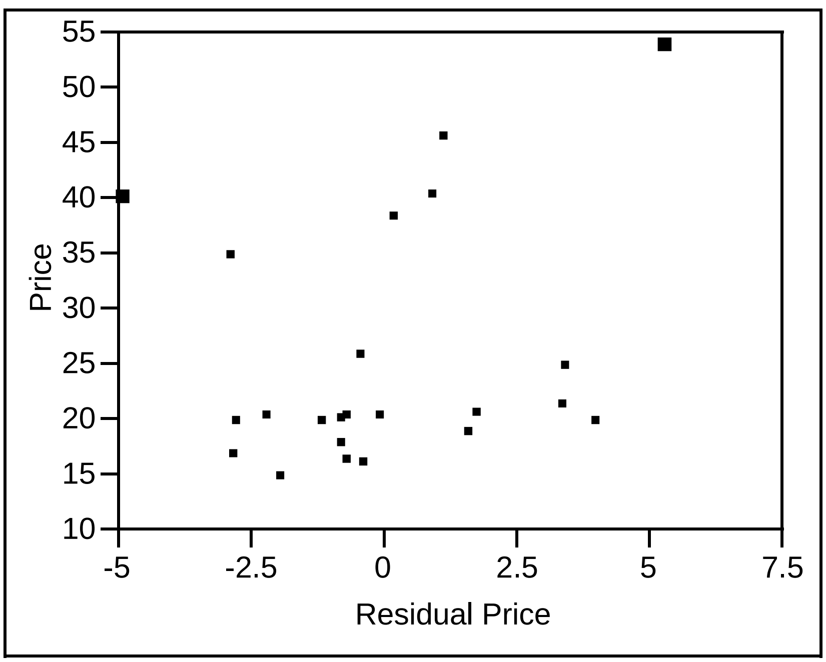

Figure A-4: Wells Drilled Structural Model Price by Residuals

APPENDIX B

Three tracks were used forecasted from 2005 to 2030: very tight supplies, tight supplies and limited constraint. All three tracks used the EIA's forecasted GDP deflator, but supply capacity constraint was varied based on the track being forecasted. The very tight supply began with a constraint variable of 1 and increased over five years to 1.5. This track represents a dramatic reduction in the world's ability to produce oil, such as Simmons' hypothesis regarding the heath of the Saudi Arabian oil fields proving correct coupled with a slow development of alternate resources. The tight supply track maintained a supply capacity constraint of 1 throughout the forecast. This represents current world production growth at a about the same rate as world income. Finally, if the world's production picks up, it is possible for the capacity constraint to return to 0.5. While it is conceivable that the world's production could remove this constraint, most likely the constraint would return as the world production slowed under the waning prices that this would bring. I believe the limited supply track is the most likely track. Further this is consistent with the findings by Gately.

Table A2-1 displays the Forecasted prices the three tracks as well as the 2006 Annual Energy Outlook forecasted price and Gately's forecasted price based on an OPEC growth rate of 1 and 2 percent. Because I did not have access to a reliable forecast for the number of wells drilled in the US, I used an ARMA (4, 4). The actual price for 2005 is the average of the price posted in the EIA's *Monthly Energy Review* for January 2006 for the months of January 2005 to November 2005. Figures 2A-1 and 2A-2 compare the three tracks of each method to the EIA forecast.

Table B-1: Forecasted Prices

Year	Actual Price	ARMA Very Tight	ARMA Limited	ARMA Tight	WELLS Very Tight	WELLS Limited	WELLS Tight	EIA (AEO, 2006)	OPEC 1% Growth (Gately, 2001)	OPEC 2% Growth (Gately, 2001)
2003	28.37	24.79	24.79	24.79	27.04	27.04	27.04	28.46		
2004	37.06	36.19	36.19	36.19	39.48	39.48	39.48	35.99		
2005	48.65[e]	38.21	36.67	36.67	41.68	40.01	40.01	49.70		
2006		37.97	34.90	34.90	41.42	38.07	38.07	53.95		
2007		37.53	31.38	32.92	40.94	34.24	35.91	51.46		
2008		41.63	32.42	35.49	45.42	35.37	38.72	48.98		
2009		42.37	30.09	34.69	46.23	32.82	37.85	46.49		
2010		43.58	29.75	35.90	47.54	32.46	39.16	43.99	32.53	23.45
2011		45.71	30.35	38.03	49.87	33.11	41.49	43.78		
2012		46.05	30.69	38.37	50.24	33.48	41.86	43.59		
2013		47.26	31.90	39.58	51.56	34.80	43.18	43.39		
2014		47.40	32.04	39.72	51.71	34.95	43.33	43.19		
2015		47.12	31.76	39.44	51.40	34.65	43.03	43.00		
2016		47.98	32.62	40.30	52.35	35.59	43.97	43.39		
2017		49.22	33.86	41.54	53.70	36.94	45.32	43.78		
2018		49.66	34.30	41.98	54.18	37.42	45.80	44.19		
2019		50.47	35.11	42.79	55.06	38.30	46.68	44.59		
2020		50.44	35.08	42.76	55.03	38.28	46.66	44.99	37.07	32.86
2021		50.45	35.09	42.77	55.04	38.28	46.66	45.59		
2022		51.04	35.68	43.36	55.69	38.93	47.31	46.19		
2023		50.79	35.42	43.11	55.41	38.65	47.03	46.80		
2024		50.62	35.26	42.94	55.23	38.47	46.85	47.39		
2025		50.96	35.60	43.28	55.59	38.84	47.22	47.99		
2026		50.91	35.55	43.23	55.54	38.78	47.16	48.39		
2027		50.90	35.54	43.22	55.53	38.77	47.15	48.80		
2028		51.33	35.97	43.65	56.01	39.25	47.63	49.19		
2029		51.10	35.74	43.42	55.75	38.99	47.37	49.58		
2030		51.67	36.31	43.99	56.37	39.62	47.99	49.99		

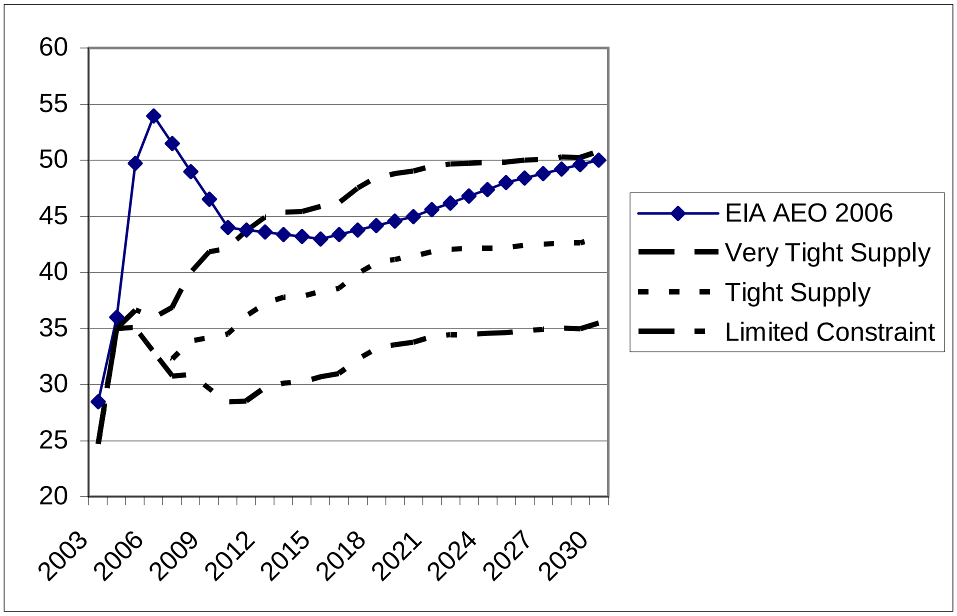

Figure B-1: ARMA Forecast v. EIA

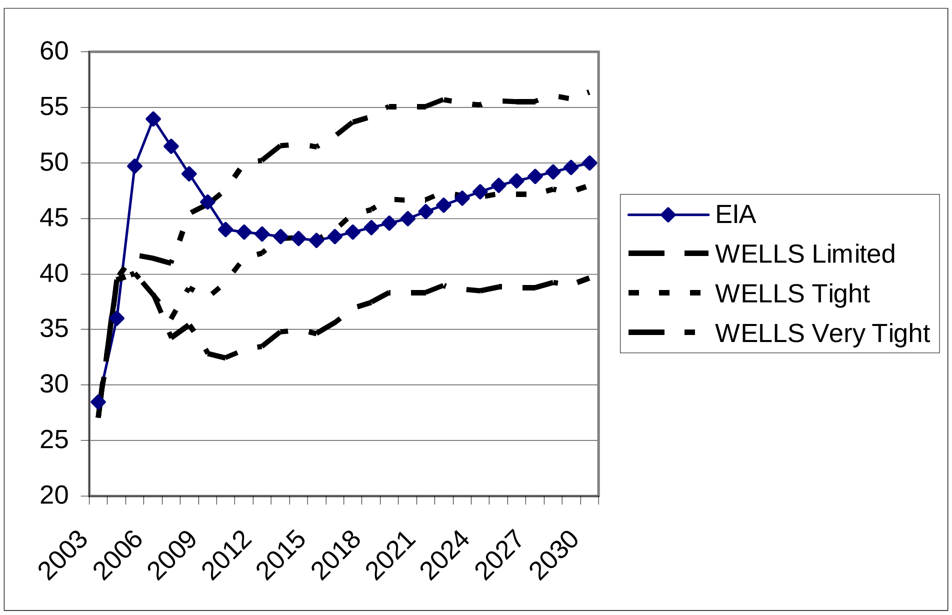

Figure B-2: Wells Drilled Forecast v. EIA

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14. ABSTRACT

Skyrocketing fuel prices have stressed the Department of Defense's budget in recent years. In 2001 the DoD spent $4.7 Billion on fuel with the Air Force consuming $ 2.7 Billion. These figures have grown over due to these increases as well as the increased flying ours to support the Global War On Terror. In fact, the Fiscal Year 2007 budget has already been increased by $1.1 billion, or 1% of the total budget, to accommodate the increased price of fuel. Current forecasts of this resource have yielded poor results, impairing the DoD's ability to budget this critical expense. Further because the forecast are poor, strategic hedging strategies cannot be effectively employed. Because fuel is a significant portion of aircraft operations and maintenance cost it should be considered in the acquisition of new systems, but the current forecast have not provided the accurate data required.

Current forecast available to the DOD were examined, and compared to two econometric structural forecast models. The performance of these structural models was then compared to the benchmark forecasts for energy provided by the Energy Information Agency. A consensus price forecast was constructed from these alternative forecasts.

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