AN ESSAY ON THE ESTIMATE

OF U.S. DEMAND FOR CRUDE OIL

THESIS

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF CHARTS

Page

ABSTRACT

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by

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SUPERVISING PROFESSOR: PAUL R. GOWENS

This paper investigates the structure of the global crude oil market and develops a model to examine U.S. demand for crude oil and to estimate the short–term price elasticity of demand for crude oil in the U.S. Historically, fluctuations in the price of crude oil have resulted from events of a political, economic, and/or financial nature. This paper describes five features of the world crude oil market that are important in understanding how this market functions: product characteristics, operation and refining, reserves and supply, demand, and price. Finally, this paper uses a modified form of the Nerlove lagged-variable model to predict U.S. demand for crude oil. The dependent

variable in this model is U.S. per-capita demand for crude oil. The independent variables in this model include the real price of U.S. crude oil, U.S. per-capita real Gross Domestic Product (GDP), U.S. per-capita demand for crude oil lagged one year, and the U.S. energy-consumption-to-GDP ratio. The exponent of the price term in the model is a measure of short-term price elasticity of demand. Therefore, the model can be used to measure the short-term price elasticity of demand for U.S. crude oil. Additionally, this paper will examine the trend in short-term price elasticity of demand for U.S. crude oil, compare these values to previous estimates, and attempt to explain any deviations about the trend.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Preamble

"Why does the world crude oil price fluctuate so much?" Because of recent price increases in gasoline, and because of the physical relationship between crude oil and gasoline, this is a question people are asking right now because of recent price increases. It is an important question because high levels in the price of crude oil affect quantity demanded for this product. Due to the fact that crude oil by-products are used on a daily basis and higher energy costs lead to higher product prices, consumers' purchasing power is reduced ("A Burning Question," 2004).

Given that energy usage is influenced by population and real GDP, and given that population growth and real GDP can be predicted with reasonable accuracy, it seems that U.S. demand for crude oil would be reasonably predictable. However, technological developments that allow energy to be used more efficiently create a downward pressure on demand.

Additionally, the size of crude oil reserves, the costs of refining and operation, the state of economy, and political affairs may serve as factors in affecting world crude oil prices. Meanwhile, crude oil prices also affect global economic activities, energy consumptions, and the costs of transportation. Consequently, it is difficult to say which, and in what combination these factors cause the price of crude oil to change. For example, according to Brown, Yücel, and Thompson (2003), a weak relationship between the price of crude oil and economic activity occurred in the United States, the world's largest crude oil consuming country. A decline in the energy-consumption-to-GDP ratio since the 1970s and strong productivity in the 1990s boom may have triggered this situation. The United States accounts for one-fourth of total world crude oil consumption. Since the U.S. is such a large consumer, it exerts excessive pressure on the price of world crude oil. Therefore, it is important to analyze historical trends in the U.S. crude oil market in order to examine the relationship between the price and quantity demanded of crude oil.

Limitations of the Study

Since the middle of the 19^{th} century, crude oil by-products have been used widely as a valuable energy resource and have become the largest traded commodity in the world market. Because of its unique characteristic and commercial value, the behavior of the crude oil market is an intriguing subject. A number of research papers related to this market have been investigated in an effort to establish a model that describes the behavior of crude oil market. However, many factors affect demand and/or supply of crude oil and because of shifts in either the demand or supply curves, or both simultaneously, the price of crude oil fluctuates unpredictable.

Due to time constraints, we develop a demand function that uses limited information to describe the behavior of demand for crude oil in the U.S. This model accurately predicts demand for crude oil and allows us to examine the relationship between price and quantity demanded in the U.S. One of the limitations in this study is lack of availability of secondary data for the model. Most secondary data are annual data which means that we cannot use the model to consider changes during the year.

Another limitation of this study is that we do not take into account such factors as the effect of supply, substitute energy, trading activities, and government policy because these considerations are uncertain and subject to political factors and the unpredictable nature of technological discovery. Sometimes these factors have limited or non-existent impact on the crude oil market; at other times they influence the crude oil market significantly. In order to make this model measurable, these factors are not included in this model.

Objectives and Organization of the Thesis

Objectives of the thesis

Crude oil, the raw material for all petroleum products, provides about 37% of global energy consumption and 97% of the world's transportation fuels. It therefore plays an important role in global economic activities (BP – Statistical review data). Since the middle of the 19th century, crude oil by-products have been widely used by manufacturers and industries, and are now essential to the conduct of modern daily life. Since then, crude oil has been the largest traded commodity in the world market. Moreover, crude oil can be used for the purpose of military strategy. For instance, in some special cases, such as conflicts between nations, crude oil becomes a political property used by one, or group of nations, to gain advantage over another nation, or group of nations. In other words, the shortage of crude oil can affect not only the global economy but also the state of political affairs. As a result, crude oil can be considered the most important energy resource we have.

Consequently, the purpose of this thesis is to examine a combination of factors that influence demand and price in the world crude oil market, including product characteristics, operation and refining, and reserves and supply. Using U.S. crude oil market data, this thesis estimates a modified form of the Nerlove lagged-variable model to predict U.S. demand for crude oil and to estimate the short-term price elasticity of demand for U.S. crude oil. Finally, this paper will examine the trend in short-term price elasticity of demand for U.S. crude oil, compare these values to previous estimates, and attempt to explain any deviations about the trend.

Organization of the thesis

Chapter 1

This chapter provides readers with an overview of the thesis. It discusses the objectives of the thesis, which include the importance of crude oil in the world energy market and the findings of the paper. Furthermore, the limitations of the study and the organization of the thesis are presented in the chapter. Finally, it presents a brief review of literature of economic theories and empirical models related to the structure of the crude oil market.

Chapter 2

To provide an understanding of the structure of the world crude oil market, this chapter is divided into five sections:

2.1 Product characteristics: This section establishes the fact that crude oil is a non-renewable resource and points out the importance of crude oil and its by-products to continued economic development.

2.2 World crude oil operation and refining: Since crude oil is a natural resource, the primary expenses related to converting crude oil to a usable form of energy are exploration and operation costs. According to data gathered in connection with this study, these costs and other considerations vary among oil-exporting nations. High operation costs in developing countries can result in higher crude oil prices. Since crude oil is a raw organic material, it cannot be used as an economic energy resource until it is distilled. In light of this fact, this section also addresses the crude oil refining process.

2.3 World crude oil reserves and supply: Researchers predict that current world crude oil reserves are sufficient until 2099, allowing for an increase in world population. Of these reserves, 79% are controlled by OPEC, which now accounts for 42% of market share. On the other hand, non-OPEC nations control only 21% of the world's crude oil reserves, but meet 58% of the world demand, estimated in 2000. This section investigates the link between crude oil reserves and supply.

2.4 World crude oil demand: Based on economic theory, price level is determined by the interaction of supply and demand. When demand changes (i.e., increases or decreases), price changes in the same direction as the change in demand. When supply changes (i.e., increases or decreases), price changes in the opposite direction as the change in supply. When demand and supply change simultaneously, price may increase or decrease depending on whether supply increases and demand decreases, or vice-versa, or depending on which change overwhelms the other. With the growth of population and development of industries, historical data indicate an upward trend in the consumption of petroleum liquids. Given this upward trend in demand over time, expect perhaps during periods of depressed economic conditions, oil-exporting countries can influence the price of crude oil by acting as a cartel to control the level of production.

2.5 World crude oil price: A number of researchers have studied the price fluctuations or volatility of the crude oil market. Because the price of crude oil is so unstable and is so closely related to other economic factors, any single event that affects either demand or supply, or both simultaneously, can cause the price to rise or fall.

Chapter 3

This chapter discusses short-term price elasticity of demand of crude oil and applies these concepts to the U.S. crude oil market. By modifying the Nerlove lagged-variable model, this section develops a version of the model which contains four explanatory independent variables such as the real price of U.S. crude oil, U.S. per capita real GDP, U.S. per capita demand for crude oil lagged one year, and U.S. energy-consumption-to-GDP ratio. The model is used to examine the relationship between the U.S. demand for crude oil and a set of explanatory variables. The exponent of the price term can be used to represent the short-term price elasticity of demand for U.S. crude oil. An overview of the U.S. economic activities is addressed at the end of the chapter.

Chapter 4

This chapter follows a regression statistics process to test the null hypothesis by collecting annual data of dependent and independent variables from 1960 to 2003. The model is applied to each of the twenty-four 20-year periods (e.g., 1961-1980, 1962-1981, 1963-1982 … and 1984-2003). The test is based on the adjusted R^2 and the overall F statistic at a 0.05 level of significance, followed by an analysis of the results of the test and a detailed explanation of the methodology of determination. Finally, this chapter presents an analysis of short-term price elasticity of demand for U.S. crude oil and an estimate of an equation for predicting U.S. demand of crude oil.

Chapter 5

This chapter summarizes the findings of the study and offers recommendations. It provides useful information for future research.

Crude Oil Market Structure Studies

The literature on the crude oil market related to production, consumption, and price has been investigated by a number of researchers. However, because of the commercial value of crude oil, OPEC and other political forces have combined to change the market structure over time. Because there are so few large producers of crude oil, the market is oligopolistic in nature and susceptible to the formation of cartels which provide substantial market power with ability to influence price by controlling supply. However, cartels are inherently unstable, tend to break up, and have to be reorganized to sustain such market power. Therefore, the market for crude oil has become unpredictable.

Crude oil is produced by OPEC and non-OPEC countries. By collecting data for both global and OPEC proved reserves, Radler (2000) concluded that there has been a slight increase in crude oil and natural gas reserves during the past 10 years. According to Radler's paper, OPEC currently controls 79% of the world's crude oil reserves and provides 42% of market supply which means that OPEC, by acting like a cartel, has the power to influence crude oil prices in the market. Most researchers believe that OPEC behaves like a cartel and only a few alternative theories have been advanced to explain OPEC's behavior. For example, for the data period from 1971 to 1983, Griffin (1985) tested an individual country's oil production level, including 11 OPEC and 11 non-OPEC countries, using the following four models: cartel, competitive, target revenue, and property rights. The results of the hypothesis tests are in favor of the OPEC cartel model, and non-OPEC competitive model. Jones (1990) continued applying Griffin's model by using quarterly data to test 11 OPEC countries for the period between 1983 and 1988. His results supported Griffin's model. However, Ramcharran (2002) pointed out a flaw in their tests, and then used the data period from 1973 to 1997, which includes the era of price increase (1970s) and price decrease (1980s –1990s), to test theses four models. By estimating the supply function of $\ln Q = \alpha + \gamma \ln P + \beta T$, the results are in favor of the target revenue hypothesis. Furthermore, Ramcharran addressed the reasons that OPEC would lose its market share and concluded that OPEC would face a challenging future.

Since crude oil by-products have been used on a daily basis in modern life, the fluctuations in the crude oil price may affect the behavior of energy consumption. From Reynolds' (2000) viewpoint, reducing crude oil production and raising its price in advance can help people conserve the consumption of crude oil. Because of the fact that crude oil reserves are decreasing, Reynolds supported OPEC conservation efforts and recommended oil-exporting countries to cut back crude oil production in order to avoid an energy crisis; otherwise, there will be a rapidly increasing price in the future. In addition, Butler (2004) pointed out the fact that crude oil by-products have been heavily used in most industries. If costs of raw material in connection with crude oil increase too rapidly, consumers still need to pay for the price even thought many researchers attempted to find a substitute resource and/or to redesign products such as automobiles. Ghanem, Lounnas, and Brennand (2000) also believed that crude oil demand would drop when the price moved above $30 per barrel. OPEC's market share would shrink as a result. In their paper, they concluded that price elasticity will change according to the rising and falling prices.

Most oil-exporting countries depend solely on the income earned from crude oil. In their paper, "An analysis of factors affecting price volatility of the U.S. oil market," Yang, Hwang, and Huang (2002) pointed out that a decreasing price would cause the oil-producing countries some serious problems, such as economic recession, social dissatisfaction, or even political instability although it might not necessarily affect the amount of production and consumption. An increasing price, however, usually comes with a reduction in the output. Consequently, Yang et al. concluded that OPEC is more likely to develop the strategy of lowering the production and raising the price. Additionally, they found that crude oil price would increase when OPEC cuts production by 4% unless the reduction in crude oil output produces a severe recession.

The Nerlove model has been used widely to test the production of crude oil. This paper also uses the modified Nerlove lagged-variable model, $Q_t = AP_t^{b}Y_t^{c}Q_{t-1}^{d}E/G_t^{e}\varepsilon_t$, to predict the U.S. demand for crude oil. The multiplicative model can be transformed in terms of logarithmic form, $\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + e\ln E/G_t + \varepsilon_t$, where Q_t is U.S. per-capita consumption of crude oil in year t; P_t is the real price per barrel of U.S. crude oil in year t; Y_t is U.S. per-capita real GDP in year t; Q_{t-1} is the distributed lag term (i.e., U.S. per-capita consumption of crude oil in year t-1); E/G_t is the U.S. energy-consumption-to-GDP ratio, and ε_t is random error in Q_t for observation t. The coefficient of the price term, represented as b, can be used to interpret the short-term price elasticity of demand for U.S. crude oil. According to Atkins & Jazayeri (2004), the most common specification used in the academic literature to test the price elasticity of demand is $D_t = \beta_0 + \beta_1 P_t + \beta_2 Y_t + \beta_3 D_{t-1} + \varepsilon_t$ (i.e. without considering the energy-consumption-to-GDP ratio). They summarize a literature review of demand studies in world oil markets, which contains estimates of the price elasticity of demand in that market. References in their paper related to short-term price elasticity of demand in crude oil market include Brown & Philips (1989), Dahl (1993), Gately & Huntington (2002), and Cooper (2003).

The above results, Brown & Philips estimated the short-term price elasticity of demand for U.S. crude oil to be -0.08 over the period between 1972 and 1988; Cooper had a result of -0.06 over the period from 1979 to 2000. This suggests that short-term price elasticity of demand for crude oil is highly price-inelastic and the estimates of short-term price elasticity vary based on the different periods of time.

CHAPTER II

THE WORLD CRUDE OIL MARKET

Product Characteristics

Crude oil is a raw organic material, also known as pre-product of petroleum, which is found underground in various forms. It is the result of a multi-million year process involving prehistoric creatures, which, after having died, sank into layers of the earth under great heat and pressure. During this period, these deposits converted into hydrocarbons, which are chemical compounds made up of mostly carbon and hydrogen atoms to create a resource of varied potential use. Crude oil contains many elements as presented in Table 1 and 2. Usually, natural gas is found in conjunction with deposits of crude oil. When the crude oil deposits were first found, simple digging and drilling processes were applied to extract crude oil from the ground. Now, oil drilling operations have become more difficult and more expensive because readily available deposits of crude oil have become scarcer. Oil exploration efforts have had to take into consideration other sources of crude oil such as shale. In order to be useable for economic products, crude oil has to go through a manufacturing process called "refining," which contains distillation and then may continue going through chemical processes by breaking down (cracking), combining (unification), or rearranging (alteration) (Freudenrich, 2001).

Table 1: The components of crude oil

The components of crude oil	
Element	**Percentage**
Carbon	84%
Hydrogen	14%
Sulfur	1~3%
Nitrogen	< 1%
Oxygen	< 1%
Metals	< 1%
Salts	< 1%

Table 2: Hydrocarbons

Hydrocarbons (straight chains – branched chains – rings)				
Categories	General formula	Description (structures)	Forms	Example
Paraffins	C_nH_{2n+2}	straight- or branched-chain molecules	gases, liquids	methane, ethane, propane, butane, isobutene, pentane
Aromatics	C_6H_5 -Y	ringed structures with one or more rings	liquids	benzene, naphthalene
Napthenes or Cycloalkanes	C_nH_{2n}	ringed structures with one or more rings	liquids	cyclohexane, methyl cyclopentane
Alkenes	C_nH_{2n}	linear or branched chain molecules containing one carbon-carbon double-bond	gases, liquids	ethylene, butane, isobutene
Dienes and Alkynes	C_nH_{2n-2}	linear or branched chain molecules containing one carbon-carbon double-bond	gases, liquids	acetylene, butadienes

(Note. n is a whole number, usually from 1 to 20. Y is a longer, straight molecule that connects to the benzene ring. Table 1 & 2 from "How Oil Refining Works," by C C. Freudenrich, 2001. Copyright 2004 by HowStuffWorks, Inc.)

Although humans have known about oil since the 3rd century B.C.E., petroleum did not become a valuable natural resource until the middle of the 19th century. In the present time, manufacturers and industries use crude oil and its by-products widely. Moreover, oil affects humans' lives in a variety of ways. A short list includes transportation and heating fuel, plastic products, clothing, drugs, synthetic fibers and rubbers, detergents, and chemical fertilizers. Crude oil is so important that it is sometimes called black gold ("Merriam -Webster's Collegiate Dictionary," 1993). According to the report of U.S. Department of Energy, Energy Information Administration (EIA), petroleum will continue to be the primary energy resource in the world, especially in developing countries, such as China and countries in Central America.

World Crude Oil Operation and Refining

When crude oil was first used for commerce in the United States in the 19^{th} century, it was stored in wooden barrels. Hence, the measurement of crude oil is in barrels.[1]

Crude oil is a naturally-occurring resource; however, it takes several million years to form. Therefore, when humans run out of these deposits, they either have to use new methods to locate oil pockets, converting crude oil into useful oil by-products, or develop alternative resources of energy. Typically, the earth's crust contains different mixtures of plant and animal remains in many regions; however, the level of these remains makes a big difference. When the quality and quantity of petroleum can be developed for the purpose of economic activity or commercial value, this oil reserve is defined a proved reserve. Unfortunately, many oilfields fall below a standard level and are therefore not counted. Generally, only 30% of oilfields are proved oil reserves, according to EIA.

To identify a prospect, drilling companies have to use technological equipment, which includes core sampling and seismic testing to measure a well, and then drill to confirm whether it is a proved reserve or not. When there is no oil or gas, or the reserve is not qualified to be developed for economic use, this oilfield is categorized as an unsuccessful well called a dry hole; on the other hand, a successful well, once identified, will continue to be tested and estimated for further drilling (see Figure 1).

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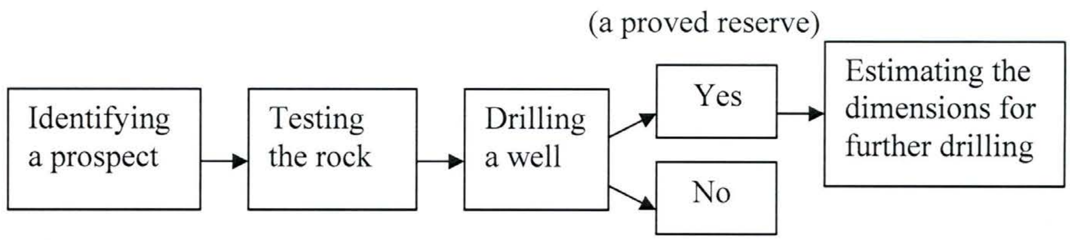
[1] 1 barrel = 42 gallons = 159 liters

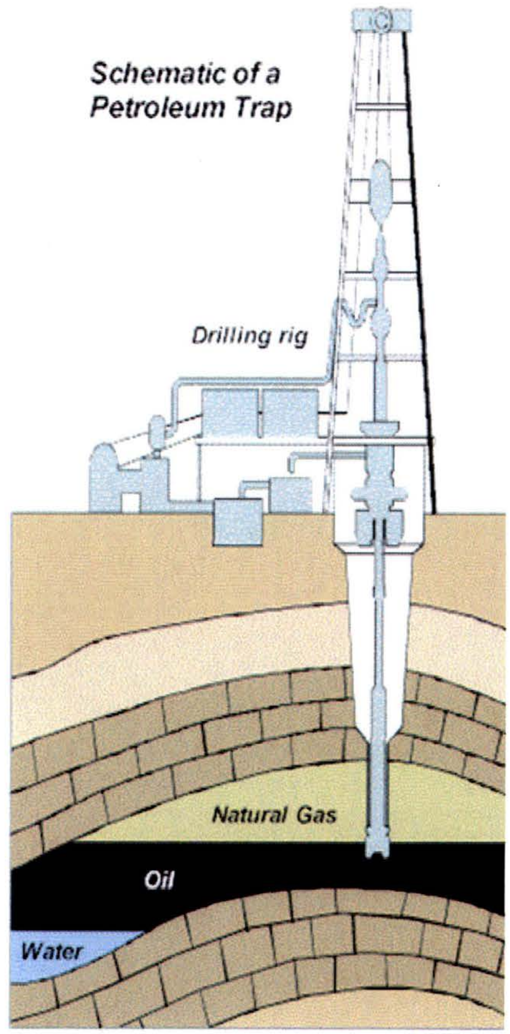
Figure 1: Steps of finding oil



(Note. Source from EIA, http://www.eia.doe.gov)

Typically, there are three different production methods for drilling oil. Natural lift, the most used means of production in the Middle East, involves forcing oil to the surface by means of the naturally occurring pressure underground. When the natural underground pressure dissipates or disappears, oil is no longer forced out naturally. Therefore, either the method of artificial lift or of artificial lift with waterflood must be used. Artificial lift involves drilling for oil using a pump powered by gas or electricity. However, a drilling rig can only reach a certain level. Below this depth, the means of waterflood has to be used to displace oil to the drilled shaft (see Figure 2).

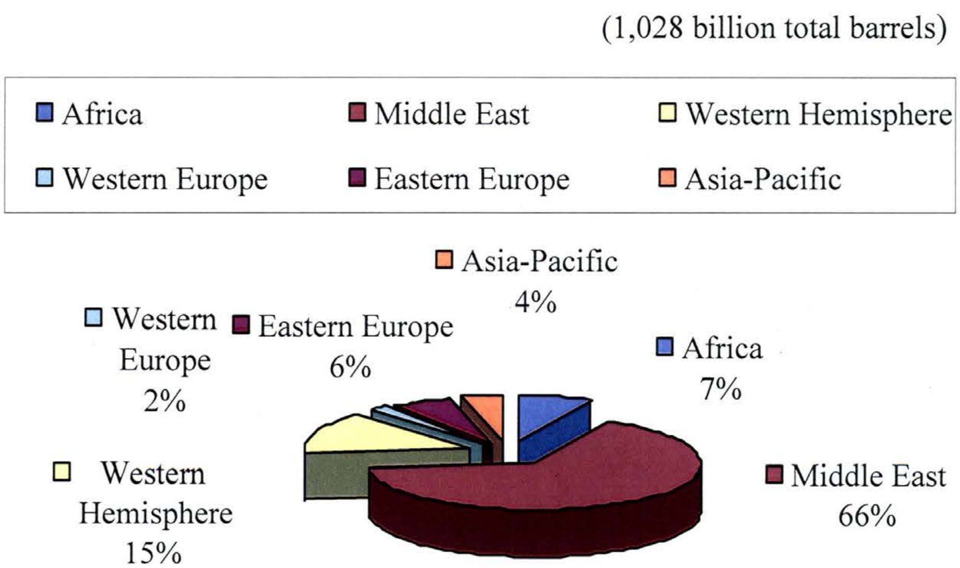
Figure 2: Petroleum trap



(Note. Form EIA, http://www.eia.doe.gov)

Consequently, drilling costs vary due to different characteristics of different reserves. For instance, the Middle East is the region that contains the richest deposits and the largest amount of crude oil (see Chart 1). The majority of oil reserves in this area can be produced by using natural lift, and it costs only $2 per barrel. In contrast, about half of the oilfields in the United States have to be produced by using artificial lift, which may cost as much as $15 per barrel. The wide range of drilling costs influences the price of crude oil. Due to the expenditures of time, effort, and money, most companies avoid drilling wildcat wells,[2] according to EIA.

Chart 1: Global proved reserves, January 1, 2001



(Note. Data source from "World Crude and Natural Gas Reserves Rebound in 2000," by M. Radler, 2000, *Oil &Gas Journal*, *98*, p. 122-123.)

[2] A wildcat well is a well in an oilfield that has not yet been discovered. (Historically, it has a low chance of success.)

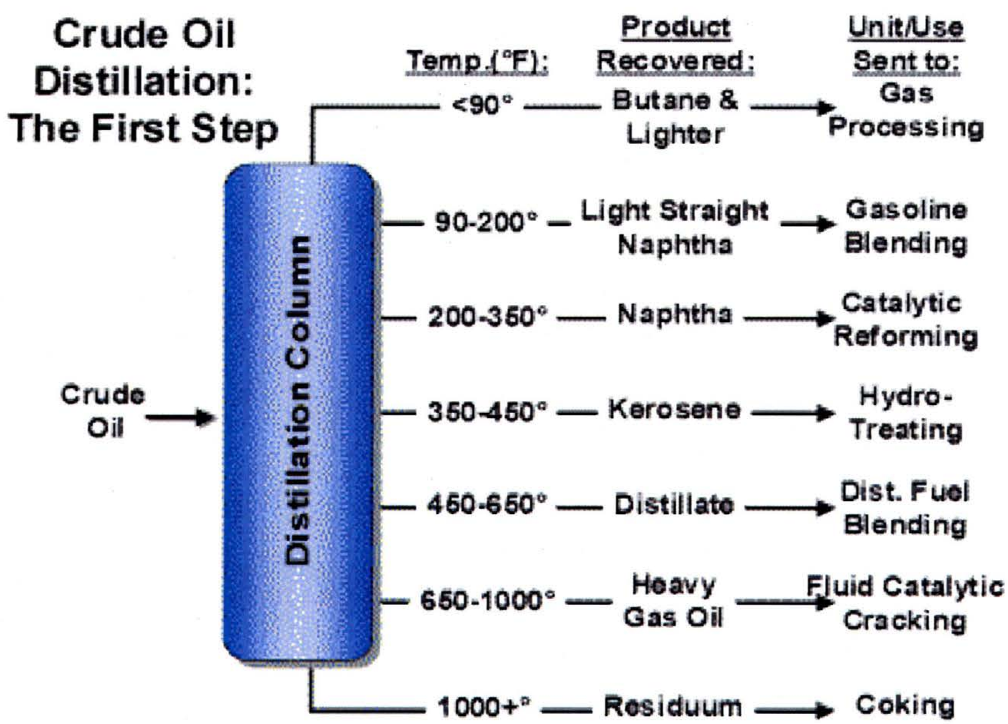
Crude oil contains a great deal of energy as well as impurities. Because of these impurities, crude oil cannot be applied as a useful resource until it is distilled. The process of separation, which follows the distillation of crude oil, is known as oil refining. Refining involves the separation of crude oil into several distinct categories such as gasoline, distillate fuel oil, and kerosene-type jet fuel. Oil refineries are comprised of a set of large, round or cylindrical tanks with a complex jungle of towers and pipes. An example of an oil refinery is displayed in Figure 3.

Figure 3: Spherical storage tanks of an oil refinery in Texas

(Note. From DISCovering science from Gale, http://galenet.gale.com)

There are two steps in the refining process – fractional distillation and chemical processing. During fractional distillation, the beginning of the process, crude oil is heated until it vaporizes and is then broken down into useful resources. Because different types of hydrocarbons have different vaporization temperatures, their boiling points can range from anywhere between less than 90 °F and larger than 1000 °F (i.e., 32.2 °C to 537.8 °C) (see Figure 4).

Figure 4: The process of crude oil fractional distillation

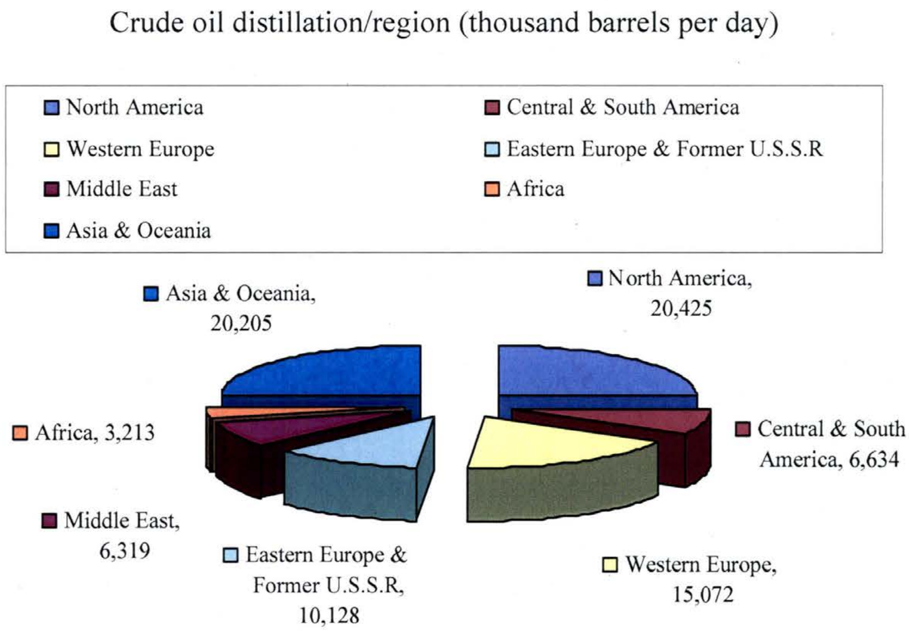


(Note. From EIA, http://www.eia.doe.gov)

Another step in processing crude oil after distillation is a relatively new technique called chemical processing. In the process of fractional distillation, only 40% of crude oil can be distilled into gasoline, one of the major products produced by the oil industries. In order to increase the yields of gasoline, chemical processing is applied. Chemists change the structures of molecules by using one of the three different methods. This process is commonly known as conversion. First, cracking breaks larger hydrocarbons into smaller units. Then, unification combines several smaller units to make one larger unit. And finally, alteration rearranges various units to make desired hydrocarbons. Diesel fuel, for instance, can be turned into gasoline by breaking longer chains (12 or more carbon atoms) into shorter ones (5 to 12 carbon atoms). After the process of distillation or conversion is completed, gasoline is ready to be used as the transportation fuel. Other crude oil by-products can also be derived from crude oil by similar processes (American Petroleum Institute, http://api-ec.api.org).

Because of different physical characteristics of crude oil, it takes a variety of processes and operation costs to produce its by-products. Since crude oil of poor quality will result in much higher refining costs, it is important for refineries to know what quality the crude oil is and how close it is to the marketplace. In addition, the advanced technology of refining can also increase the production of output and reduce the expense of producing processes. In general, oil consuming countries will develop their own refining capacity because the total expenditure of importing and distilling crude oil is less than that of importing oil by-products from oil-exporting countries. Thus, most refineries are located in the North America, Europe or Asia (see Chart 2). Among these regions of world refinery capacity, the oil industries in the United States, especially in the Gulf Coast region, including Texas and Louisiana, contain the best suppliers and technologically advanced refining equipment in the world, according to EIA.

Chart 2: World crude oil refinery capacity January 1, 2003



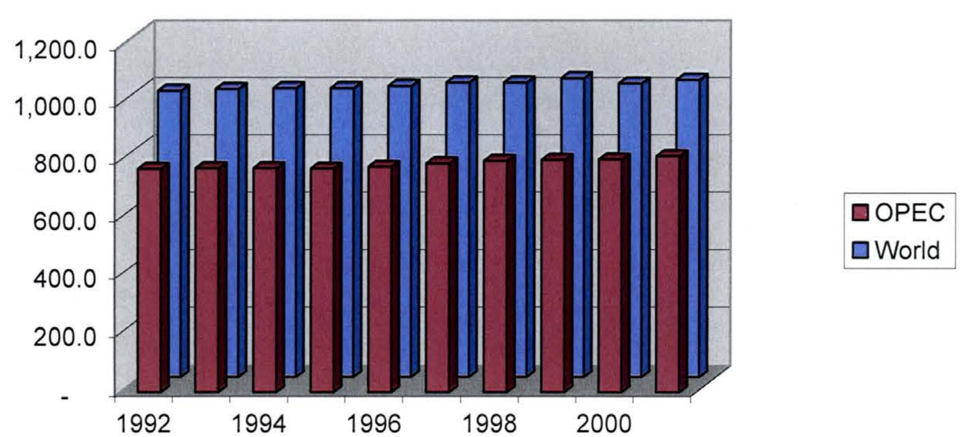
(Note. Data source from EIA, http://www.eia.doe.gov)

World Crude Oil Reserves and Supply

As mentioned earlier, a proved reserve is an oilfield whose quality and quantity of petroleum meet the standards of economic conditions. The oil-field production may reflect only a fraction of the oil that a reservoir held. Therefore, oil industries spend considerable effort in terms of time and money on oil exploration and attempt to use new techniques and methods to increase the yields of its by-products.

According to Radler (2000), the amount of world crude reserves has slightly increased. At the end of 2000, the total proved global reserves were estimated at approximately 1,028 billion barrels of crude oil (see Chart 3). Over half of the proved global oil reserves are controlled by five countries, including Saudi Arabia, Iraq, Abu Dhabi, Kuwait, and Iran, of which Saudi Arabia controls about 25.5% of global proved reserves. Moreover, the 11 OPEC member countries hold more than 79% of the total proved global reserves, and the other 21% is held by Russia, Mexico, China, the United States, etc. (see Table 3).

Chart 3: A decade of reserves changes



(Note. Data source from "World Crude and Natural Gas Reserves Rebound in 2000," by M. Radler, 2000, *Oil &Gas Journal*, *98*, p. 121.)

Table 3: Global proved reserves and oil production, January 1, 2001

Global proved reserves and oil production, January 1, 2001 (thousand barrels)					
Region	Country	Estimated proved reserves	%	Estimated oil production (bbl/d)	%
Africa	Algeria	9,200,000	0.89	800	1.19
	Libya	29,500,000	2.87	1,407.50	2.10
	Nigeria	22,500,000	2.19	1,990.80	2.97
Asia-Pacific	Indonesia	4,979,710	0.48	1,298.80	1.94
The Middle East	Iran	89,700,000	8.72	3,567.50	5.32
	Iraq	112,500,000	10.94	2,681.70	4.00
	Kuwait	94,000,000	9.14	1,774.00	2.64
	Qatar	13,157,000	1.28	680.8	1.01
	Saudi Arabia	259,200,000	25.20	8,064.00	12.02
	UAE	102,800,000	10.00	2,855.90	4.26
Western Hemisphere	Venezuela	76,862,000	7.47	3,035	4.52
Total OPEC		814,398,710	79.19%	28,156	41.96
Africa (non-OPEC)	Angola	5,412,000	0.53	743.5	1.11
	Egypt	2,947,560	0.29	810.8	1.21
	The rest of countries	5,329,883	0.52	952.7	1.42
Asia-Pacific (non-OPEC)	Australia	2,895,000	0.28	720	1.07
	China	24,000,000	2.33	3,255	4.85
	India	4,727,850	0.46	639.1	0.9
	Malaysia	3,900,000	0.38	670.8	1.00
	The rest of countries	3,454,914	0.34	777.9	1.16

Table 3: Global proved reserves and oil production, January 1, 2001 (continued)

Region	Country	Estimated proved reserves	%	Estimated oil production (bbl/d)	%
The Middle East (non-OPEC)	The rest of countries	12,158,870	1.18	1,944.80	2.90
Western Europe (non-OPEC)	Norway	9,447,290	0.92	3,216.20	4.79
	United Kingdom	5,002,795	0.49	2,536.90	3.78
	The rest of countries	2,735,271	0.27	676.5	1.01
Eastern Europe and FSU (non-OPEC)	Kazakhstan	5,417,000	0.53	627	0.93
	Russia	48,573,000	4.72	6,350.80	9.47
	The rest of countries	5,034,435	0.49	856.7	1.28
Western Hemisphere (non-OPEC)	Argentina	3,071,195	0.30	749.5	1.12
	Brazil	8,100,000	0.79	1,139.20	1.70
	Canada	4,706,000	0.46	1,998.50	2.98
	Colombia	2,577,200	0.25	688.7	1.03
	Mexico	28,260,000	2.75	3,050.40	4.55
	U.S.A	21,765,000	2.12	5,823.00	8.68
	The rest of countries	4,543,612	0.44	712.4	1.06
Total non-OPEC		214,058,875	20.81	38,940.40	58.04
Total world crude oil		1,028,457,585	100.00	67,096.40	100

(Note. Data source from "World Crude and Natural Gas Reserves Rebound in 2000," by M Radler, 2000, *Oil &Gas Journal*, *98*, p 122-123.)

Since crude oil by-products have been used by individuals on a daily basis or by industries as an important energy resource, a steady supply in crude oil becomes an essential topic for domestic policy. Some countries, such as the U.S., will keep a large reserve of crude oil for emergencies. For example, compared with the oil reserves in the Middle East, the United States only has 2% of global proved reserves, as shown in Table 3. In order to avoid a severe oil supply shortage, the Federal Energy Administration in the United States sets the Strategic Petroleum Reserve (SPR), which is an emergency supply of crude oil. The amount of oil held in the SPR was 638.39 million barrels, approximately one month of U.S. consumption, as estimated in 2003 (EIA, Strategic Petroleum Reserve, 1977-2003).

Due to the fact that crude oil is a non-renewable resource and that reserves are limited, the power of oil-exporting countries to control the market of crude oil is enhanced. The Middle East, known as the region containing the richest deposits and the largest amount of crude oil, provides approximately 32% of the world's demand. The Organization of the Petroleum Exporting Countries (OPEC),[3] the major crude oil supplier for the world, currently meets at least twice a year to discuss the price of crude oil and to determine the production quota for each of its member nations. It holds 79% of the world's crude oil reserves and about 42% of the market share (Radler, 2000).

Over the past few decades, a number of studies have been conducted that reveal the effects of OPEC's behavior on the world oil price. Some experts, however, have argued that OPEC faces a challenging future due to the rise in oil production among non-

[3] The Organization of Petroleum Exporting Countries (OPEC) was found in 1960. It currently contains 11 nations, including original members Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela, and other members, ordered by the joining time, Qatar (1961), Indonesia (1962), Libya (1962), the United Arab Emirates (1967), Algeria (1969), and Nigeria (1971). Source: OPEC official Web site, http://www.opec.org

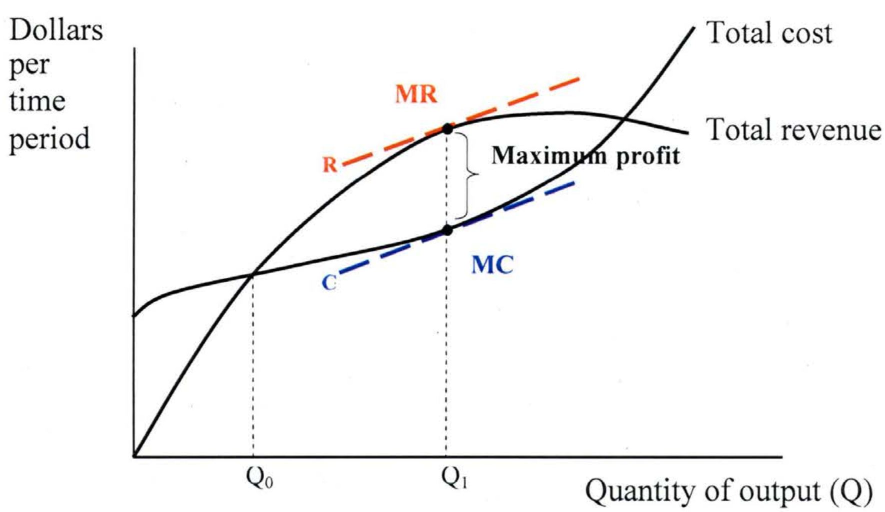
OPEC entities. This increase threatens OPEC's ability to control the price and production of crude worldwide. Although OPEC's strategy is to maximize its members' collective profit by increasing price and lowering output at the same time, the basic conflict between the collective maximum profit and the self-interested behavior of some member nations causes the OPEC model to be inherently unstable. Additionally, the war between the Gulf nations of Iran and Iraq in the1980s began to weaken the influence of OPEC, which has only been further weakened by an increase in non-OPEC supply. However, OPEC, undoubtedly, still controls the largest crude oil reserves. It is clear that the demand of the global energy markets will increase continuously. Unless a substitute energy resource is discovered or developed, the power of OPEC cannot be ignored (Alhajji & Huettner, 2000).

OPEC is an international organization, whose member nations heavily depend on crude oil revenues as their main source of income. Membership is open to any country that is a crude oil exporter and which shares the ideals of the organization. The objective of OPEC is to coordinate and unify crude oil prices among countries by supplying regular production to secure fair and stable prices for crude oil (OPEC, http://www.opec.org).

OPEC currently supplies about 42% of the world crude oil consumption, but controls more than two-thirds of the world's total proved crude oil reserves. Because crude oil is considered a primary energy resource in the world and is highly demanded by the oil-importing nations, OPEC's behavior in connection with the output of crude oil has heavily influenced the world crude oil price (Griffin & Teece, 1982). Most studies show that OPEC acts as a cartel. By definition, a cartel is a group of producers that enter into a collusive agreement aimed at controlling price and output in a market. Within the United

States, collusive agreements among producers represent violations of antitrust laws and are illegal. By contrast, countries in the OPEC participate directly. The 11 member nations of OPEC meet at least twice a year, which is known as the OPEC Conference, to discuss the price of crude oil and to determine the production quotas for each member nation. The intent of the cartel is to secure monopoly profits for its members by setting cartel marginal revenue (MR) equal to individual members' marginal cost (MC). At this quantity of output, cartel profits are maximized (see Figure 5). The goal of cartel behavior is to maximize the members' collective profit by acting as a single monopolist. However, the basic conflict is that the total production costs vary in the 11 member nations. The behavior maximizes the collective profits of the cartel and self-interested behavior on the part of individual cartel members. The result is that the cartel model is inherently unstable because individual members have an incentive to increase their output beyond the allocation assigned to them by the cartel (Samuelson & Marks, 2003).

Figure 5: Marginal-Revenue-Equals-Marginal-Cost rule



(Note. Marginal revenue = the slope of line R. Marginal cost = the slope of line C. From "Managerial Economics: Theory, Applications, and Cases, 6th ed.," by W. B. Allen, N. A. Doherty, K. Weigelt, and E. Mansfield, 2005, p. 65. Copyright 2005 by Norton & Company, Inc.)

After two global oil pricing crises resulting from the Arab oil embargo in 1973 and the outbreak of the Iranian Revolution in 1979, OPEC rose to its international status by forcing its member nations to take control of their domestic oil industries. OPEC anticipated oil market developments and quickly adjusted the level of oil production. As per objectives established in the OPEC Conference, the supreme authority of the organization, OPEC's production levels were increased three times during 2004. The president of the OPEC Conference, HE Sheikh Ahmad Fahad Al-Ahmad Al-Sabah (2005) stated that "Currently, [OPEC] are monitoring closely the market … review the prevailing market outlook to ensure market stability at reasonable price" (¶ 4).

Based on economic theory, the supply curve will affect the movement of price directly. Some oil-exporting countries tried to raise their production levels in order to increase revenues. According to Ghanem et al. (2000), non-OPEC developing countries have increased their oil production every year since 1970. The 1998 International Energy Agency reference case projections used the Hubbert curve to forecast that oil production from non-OPEC developing countries will keep increasing to 14 million barrels per day by 2020. Total non-OPEC production will increase to 48.6 million barrels per day by 2020. In order to satisfy the worldwide demand, OPEC will increase its output to 54.6 million barrels and its market share will expand to 52.9% (see Table 4).

Table 4: World oil production outlook in the reference case (mbbl/d)

	1998	2000	2005	2010	2015	2020
OPEC	29 (39.5%)	30.5 (40.1%)	35.9 (42.9.0%)	41.0 (45.3%)	47.8 (49.3%)	54.6 (52.9%)
Non-OPEC	44.4 (60.5%)	45.5 (59.9%)	47.7 (57.10%)	49.6 (54.7%)	49.2 (50.7%)	48.6 (47.1%)
World	73.4	76.0	83.7	90.6	97.0	103.2

(Note. Form “Global Energy Outlook: An Oıl Price Scenario Analysıs,” by S. Ghanem, R Lounnas, and G Brennand, 2000, *OPEC Revıew, 24*, p 263)

World Crude Oil Demand

Based on economic theory, price can be simply determined by demand and supply. When demand pushes against supply, prices increase rapidly, states Reynolds (2000), an assistant professor in the department of Economics at the University of Alaska. Given the unique product characteristic and the important commercial value, global oil consumption has been considered one of the major factors affecting the world crude oil price. Reynolds declares that the factors influencing the crude oil demand will be the energy power, industrial uses, and transportation.

In the Northern Hemisphere, for example, North America, Russia and Northern Europe use crude oil by-products as an energy resource for heating. The residents in these areas, therefore, have a higher demand for oil during cold months. According to historical data, the demand for crude oil in the 1st and 4th quarters of the year is usually greater than that in the 2nd and 3rd quarters of the year (see Table 5).

Table 5: Total world demand quarterly data from 1991 to 1997 (mbbl/d)

Year	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	Average
1991	67.51	64.79	64.85	67.86	66.25
1992	68.9	65.33	65.42	68.12	66.94
1993	67.76	64.84	65.55	68.65	66.71
1994	69.80	66.57	67.62	70.33	67.54
1995	71.06	68.49	68.99	72.30	69.93
1996	72.75	69.74	70.07	73.51	71.52
1997	73.69	72.05	72.19	75.30	73.31

(Note. Data source from “Energy statistics sourcebook, 13th ed.,” p. 351-354.)

Comparing the demand for crude oil prior to the industrial revolution with the demand for crude oil presently, we detect a trend toward rising consumption, especially in developing countries. The rise of industry in various developing countries has effected changes in their economic structures, and simultaneously stimulated increased demand for crude oil by-products by such areas of industry as transportation and production. According to EIA, the industrialized countries, such as those of the Organization for Economic Cooperation and Development (OECD), used to be the largest oil consumers, accounting for almost two-thirds of the global oil consumption in the 1980s. Between 1993 and 2003, the demand in the OECD countries increased only slightly by 13%[4] in comparison to the demand in non-OECD countries, which saw an increase of 28%[5] (see Chart 4). Generally speaking, developed countries using crude oil and its by-products tend to be more dedicated to its efficient use than developing or un-developed countries, even though the developed countries have a greater demand of the resource than other countries.

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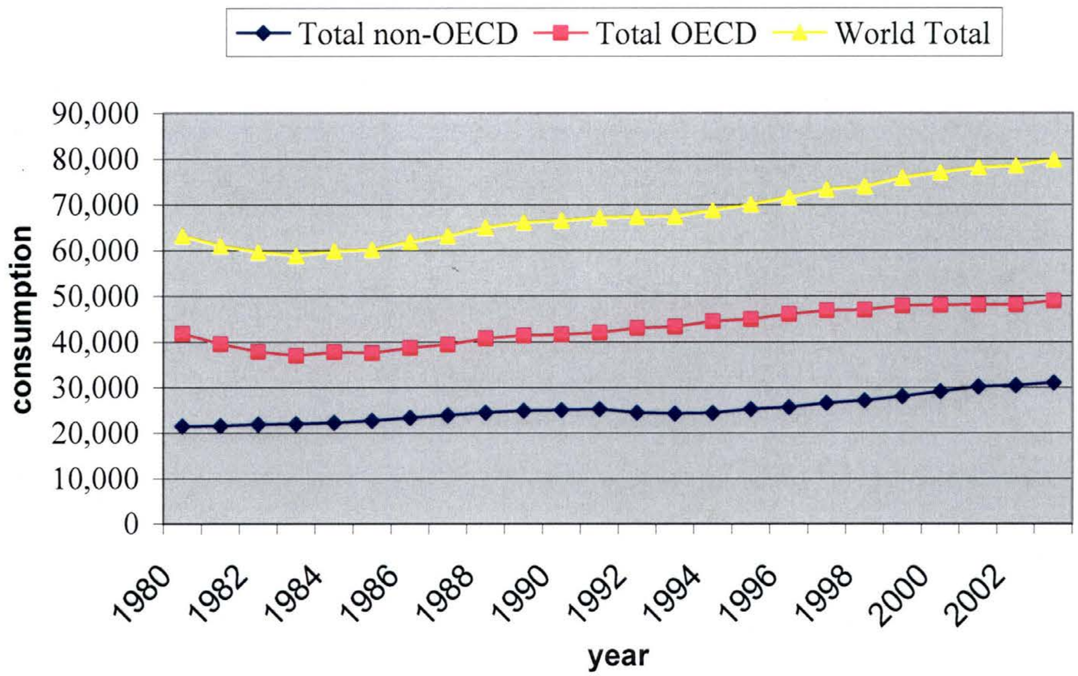
[4] Crude oil demand of total OECD: in 1993 - 43,259,000 barrels per day, in 2003 – 48,883,000 barrels per day Source: U.S Dept of Energy, Energy Information Administration, http://www.eia.doe.gov

The rate of increase from 1993 to 2003 is $\frac{48{,}883{,}000 - 43{,}259{,}000}{43{,}259{,}000} = 13.0\%$.

[5] Crude oil demand of total non-OECD: in 1993 - 24,113,000 barrels per day, in 2003 – 30,930,000 barrels per day Source: U.S Dept. of Energy, Energy Information Administration, http://www.eia.doe.gov

The rate of increase from 1993 to 2003 is $\frac{30{,}930{,}000 - 24{,}113{,}000}{24{,}113{,}000} = 28.3\%$.

Chart 4: Crude oil demand, 1980-2003 (thousand barrels per day)



(Note. Data source from EIA, http://www.eia.doe.gov)

According to a report from BP – Statistical review data, the use of petroleum for transportation fuels accounts for 97% of crude oil by-products. In developed countries, most residents have their own vehicles and live far away from the work place. The commute to and from work every day creates a great demand for oil as a transportation fuel. Recently, the growing sales of vehicles in developing countries such as China and India may lead to an increase in crude oil consumption. Meier, Roundtree, and Schaefer (1998) pointed out that the global population in 1950 was 2.5 billion, and the number of automobiles in existence at that time was 50 million. After a half century, however, the number of automobiles increased ten fold to 500 million, while the human population has just more than doubled. More interestingly, according to a report from the United Nations Population Division in 2000, the population of China was 1,275 million, the population of India was 1,016 million, and the population of the United States was 285 million.

However, China had only 1.8 million passenger cars, which represented 1% as many cars as those in the U.S., and India had only 2% as many cars as those in the U.S. In light of global economic developments, the Chinese car ownership is expected to rise to 180 million by 2010. Various other countries should experience similar increases, as Meier et al. suggested. Since crude oil by-products are used for most transportation fuels, such increases in the production of automobiles threaten to cause a major problem in terms of the availability of crude oil as an energy resource, stated Reynolds (2000).

According to Herrick (2004), China is now the second largest crude oil consumer in the world. It meets 5 million barrels a day, and will continue to increase its quantity demanded. The United States, the largest oil-consuming country, consumes 20 million barrels a day, which accounts for approximately one-fourth of the world's consumption. From another angle, the average consumption in China is about 1.37 barrels of oil per person per year,[6] whereas the average consumption in the United States is about 25.23 barrels of oil per person per year.[7] As stated earlier, the developed countries, specifically the United States, will be more efficient in its use of crude oil by-products than developing countries such as China. Based on these trends, strong growth in crude oil demand is foreseeable. In connection with the previous section, oil-exporting countries, especially OPEC, can easily act as price-setters by controlling the level of production. Additionally, studies have suggested that high crude oil prices are driven by ineffective

[6] The population of China in 2000 was 1,275 million; the oil consumption of China was 4 795 million/day.

$$\frac{4.795*365}{1275} = 1.37 \text{ barrels per person per year}$$

[7] The population of U.S.A in 2000 was 285 million; the oil consumption of China was 19.701million/day.

$$\frac{19.701*365}{285} = 25.23 \text{ barrels per person per year.}$$

drilling capability and strong growth in the demand. In other words, high crude oil prices will occur as a result of a strong economy. However, it will also weaken consumers' purchasing power, which may slow down the quantity demanded for crude oil and the growth of the state of the economy.

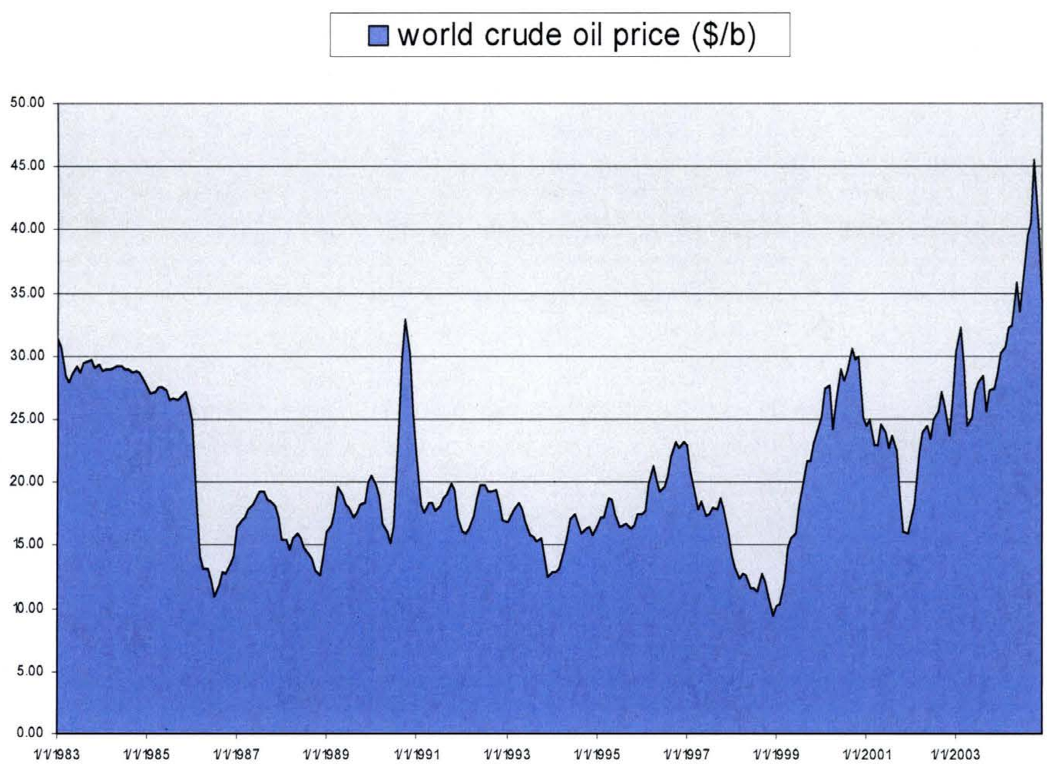
World Crude Oil Price

Since the middle of the 19th century, crude oil by-products have been essential to the conduct of daily modern life. Fluctuations in the crude oil price are affected by such factors as supply and demand. Due to shortage or oversupply of crude oil, prices can be expected to rise or fall. Meanwhile, unstable demand for crude oil creates uncertainty in the crude oil price.

A report from the International Energy Agency (IEA) ("Analysis of the Impact," 2004) analyzed the impact of high oil prices on the global economy. "Oil prices remain an important macroeconomic variable: higher prices can still inflict substantial damage on the economies of oil-importing countries and on the global economy as a whole" (p. 15). Since oil prices greatly affect the world economy, each individual nation has to justify its use of this energy resource. Generally speaking, OECD countries are more able to survive under higher oil-import costs than other developing countries because of energy efficiency in OECD countries. According to the results of a quantitative exercise from IEA, 40% of oil price increases will result in 0.4% decrease in GDP in the OECD countries. Among these countries, the United States suffers the smallest decrease, with a loss only 0.3% of its GDP. On the other hand, it is estimated that an average loss of 0.8% of GDP occurs in Asia and a 1.6% loss occurs in very poor countries and those that are highly dependent upon oil-imports. On the supply slide, the exporting countries can directly raise their real national incomes due to increases in crude oil prices. The gains from these earnings may offset the lower demand for crude oil by the trading partners during an economic recession. Overall, unstable crude oil prices will lead to changes in rates of inflation, exchange rates, quantity demanded, input costs, unemployment rates, incomes, and investments.

According to historical data, the price in the crude oil market during the past two decades was volatile (see Chart 5).

Chart 5: Monthly refiner acquisition cost of imported crude oil, defined as world crude oil price, from 1983 to 2004



(Note. Data source from EIA, refiner acquisition cost of crude oil, imported, http://www.eia.doe.gov)

Comparing the rate of change in the GDP deflator[8] since the 1980s with the rate of change in crude oil since the 1980s indicates that the price of crude oil fluctuated more

[8] GDP deflator is a price index measuring changes in prices of all new, domestically produced, final goods and services in an economy by converting output measured at current price into constant-dollar GDP. Also known as the "GDP implicit price deflator." Since the GDP deflator is not based on a fixed market basket of goods and services, changes in consumption patterns are automatically reflected in the deflator. Source: Investopedia.com, http://www.investopedia.com

than other prices as measured by the GDP deflator. In terms of the base year 2000, between 1983 and 2004, the GDP deflator has increased at a relatively stable per annum rate of approximately 2.44%,[9] fluctuating at times by 2.0% or 3.0%. However, crude oil prices exhibit a much different pattern. The Iran/ Iraq conflict represented an unusual phenomenon in the market, during which the price of crude oil fluctuated at a relatively high level, an average of $28.3 per barrel. Following the war, the rate of increase in the crude oil price returned to relatively moderate levels (see Chart 5). Consequently, the rate of increase in the price of crude oil has varied at different times during this period.

For example, between 1981 and 1986, during the Iran/Iraq War, the monthly average price of crude oil rose to $39 per barrel by February 1981. At the end of the war in 1986, the monthly average price rapidly dropped back to $10.91 per barrel. From 1986 to 2003, the monthly average price of crude oil has fluctuated between $10 and $30 per barrel. However, an upward movement in the price of crude oil has occurred since the beginning of 2004. In April 2005, the price of crude oil hit a record high of $58.28 per barrel in the United States and elsewhere (Bahree & Herrick, 2005). Extraordinary circumstances such as the 9/11 disaster and the United States' War on terrorism in Iraq are likely triggers for this increase in the price of crude oil since the beginning of 2004. Other factors may include a decision by OPEC to reduce production.

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[9] GDP implicit price deflator (2000 = 100) (annual average in 1983 = 65.19; annual average in 2004 = 108.23). Source: Economagic database, http://www.economagic.com

The rate of increase of GDP deflator = $\sqrt[21]{\frac{GDPdeflator_{2004}}{GDPdeflator_{1983}}} - 1 = \sqrt[21]{\frac{108.23}{65.19}} - 1 \approx 2.44\%$

Considering the period from the Iran/ Iraq War to 2004, the annual rate of increase in the price of crude oil was 1.15%,[10] which was lower than that of the GDP deflator, 2.44% (see note 9). However, after the Iran/ Iraq war, the price fell to $10 per barrel and the annual rate of increase in the price of crude oil rose by 5.39%[11] to an average of $36.01 per barrel in 2004. Between 1983 and 2004, the rate of change for each previous year within this range of years fluctuated between -46.95% and 60.28% (see Table 6). Meanwhile, the rate of increase from last year in the GDP deflator fluctuated very little by comparison (see Table 7). These data show that there has been a larger increase or decrease in the price of crude oil than in the price of other items represented by the GDP.

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[10] World crude oil price (the annual average price from 1981 to 1986 = $28 30/barrel; the average price in 2004 = $36 01/barrel). Source. U.S. Dept of Energy, EIA, http://www.eia.doe.gov

The rate of increase of crude oil price = $\sqrt[21]{\dfrac{36.01}{28.03}} - 1 \approx 1.15\%$.

[11] World crude oil price (the average price in 1986 = $14/barrel, the average price in 2004 = $36.01/barrel). Source: U.S. Dept of Energy, EIA, http://www.eia.doe.gov

The rate of increase of crude oil price = $\sqrt[18]{\dfrac{36.01}{14}} - 1 \approx 5.39\%$.

Table 6: World crude oil price: annual percentage change from last period

Year	Average price ($/bbl)	%		Year	Average price ($/bbl)	%
1983	29.35	-12.64		1994	15.41	-4.69
1984	28.87	-1.64		1995	17.15	11.26
1985	27.00	-6.47		1996	20.60	20.14
1986	14.32	-46.95		1997	18.55	-9.93
1987	18.05	26.00		1998	12.10	-34.80
1988	14.62	-18.98		1999	17.27	42.76
1989	18.07	23.59		2000	27.68	60.28
1990	22.20	22.87		2001	21.98	-20.57
1991	18.74	-15.60		2002	23.63	7.49
1992	18.12	-3.33		2003	27.85	17.82
1993	16.17	-10.74		2004	36.01	29.30

(Note Data source from Economagic database, http://economagic.com)

Table 7: GDP deflator: annual percentage change from last period

Year	GDP implicit price deflator	%		Year	GDP implicit price deflator	%
1983	65.19	3.93		1994	90.25	2.12
1984	67.65	3.77		1995	92.10	2.05
1985	69.71	3.65		1996	93.85	1.89
1986	71.25	2.21		1997	95.41	1.67
1987	73.19	2.73		1998	96.47	1.11
1988	75.69	3.41		1999	97.86	1.44
1989	78.55	3.79		2000	100.00	2.18
1990	81.59	3.87		2001	102.40	2.40
1991	84.44	3.49		2002	104.09	1.65
1992	86.38	2.30		2003	105.99	1.83
1993	88.38	2.31		2004	108.23	2.11

(Note. Data source from Economagic database, http://economagic.com)

CHAPTER III

AN ESTIMATE OF U.S. DEMAND FOR CRUDE OIL

A Modification of the Nerlove Lagged-variable Model

The Nerlove lagged-variable model, developed by professor Marc Nerlove of the Agricultural & Resource Economics Department at the University of Maryland, to estimate the supply of agricultural products, states that $Q_t = AP_t^{b}Y_t^{c}Q_{t-1}^{d}\varepsilon_t$.

Professor Marc Nerlove used homogeneous production function (i.e. Cobb-Douglas type), with lagged variable terms, to study demand for agriculture products (Nerlove, 1965).

The three factors of Cobb-Douglas production function is the following:

$q = f(L, K, M) = A * (L^{\alpha}) * (K^{\beta}) * (M^{\gamma})$

where

q is product, L is labor, K is capital, M is materials and supplies.

α, β, and γ are parameters.

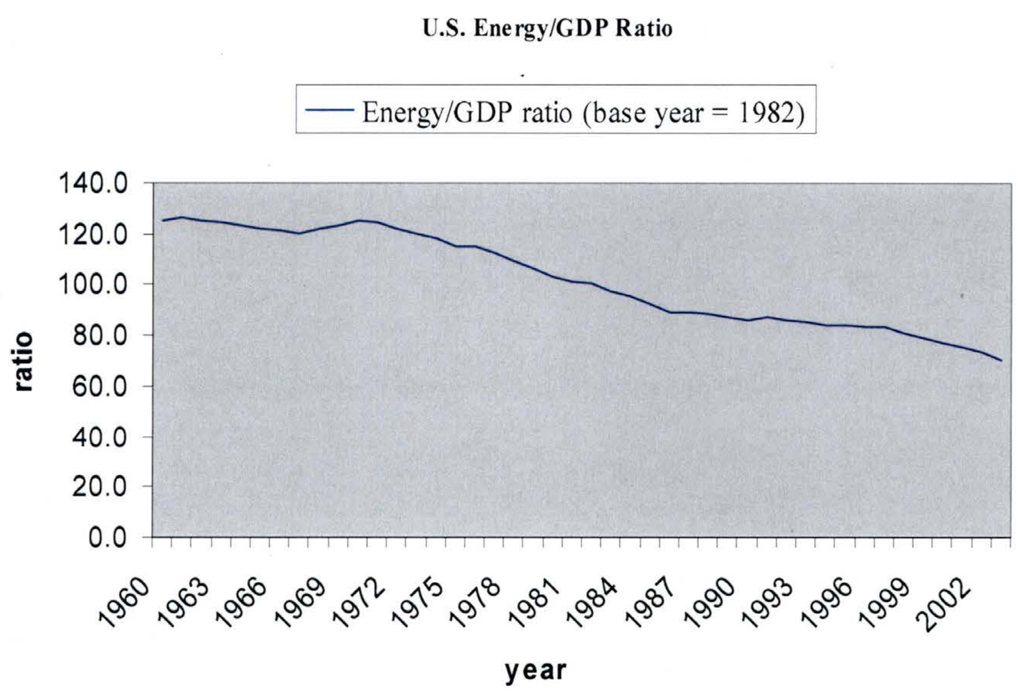
The modified model of the Nerlove lagged-variable model is used in this study to predict U.S. demand for crude oil. It can be transformed in terms of logarithmic form, $\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + \varepsilon_t$, where Q_t is U.S. per-capita consumption of crude oil in year t; P_t is the real price per barrel of U.S. crude oil in year t; Y_t is U.S. per-capita real GDP in year t; Q_{t-1} is the distributed lag term (i.e., U.S. per-capita consumption of crude oil in year t-1); and ε_t is random error in Q_t for observation t. The coefficient of the price term, represented as b, can be used to interpret the short-term price elasticity of demand for U.S. crude oil. This modified form is used in this study to examine U.S. demand in the crude oil market and to estimate how sensitively U.S. consumers respond to crude oil price movements.

The Nerlove model is a quantitative forecasting method making use of historical data involving both the projection of time series[12] and causal methods. Increased GDP causes increases in energy consumption (i.e. the growth of GDP and the energy consumption have a positive relationship), as opposed to the relationship between the price of energy and the consumption of energy. The shift of the demand curve causes the price to move in an opposite direction. Consequently, demand and price have a negative relationship. Brown et al. (2003) pointed out that the increased oil price was the result of increased demand for this product rather than supply shortage or pervious oil price shocks. However, higher energy prices contributed to the efficiency of consumers' energy consumption. In order to reduce the pressure resulting from increased oil prices, nations either seek energy substitutes or increase energy saving measures. Related to the influence of this model, U.S. energy-consumption-to-GDP ratio has declined rapidly since the mid-1970s (see Chart 6). Because of energy efficiency, U.S. oil consumption during the 1990s grew only moderately. Prior to this study, we tested the Nerlove lagged-variable model, $Q_t = AP_t^bY_t^cQ_{t-1}^d\varepsilon_t$, by using U.S. crude oil market data to test the whole period from 1960 to 2003. We found that the coefficients of real per-capita GDP terms

[12] Time series. A time series is a set of numerical data obtained at regular periods of time.

are negative in some periods such as the data period from 1970 to 1989, 1971 to 1990 …, and 1979 to 1998 (see Table 8). In order to solve this problem and reach a more accurate result, this modified model also considers the U.S. energy-consumption-to-GDP ratio as an independent variable. This allows the estimated model to reduce the size of the error terms while increasing R^2 values and to avoid specification mistakes so that the estimated model can provide an effective equation for predicting the U.S. demand for crude oil, as well as a significant exponent, which is a measure of the short-term price elasticity of demand. The multiplicative model with four independent variables is expressed as $Q_t = AP_t^b Y_t^c Q_{t-1}^d E/G^e_t \varepsilon_t$.

Chart 6: U.S. Energy/GDP ratio from 1960 to 2003



(Note. From "Business Cycles: The Role of Energy Prices," by S.P.A. Brown, M.K. Yücel, and J. Thompson, 2003. Federal Reserve Bank of Dallas, working paper 0304, p. 14.)

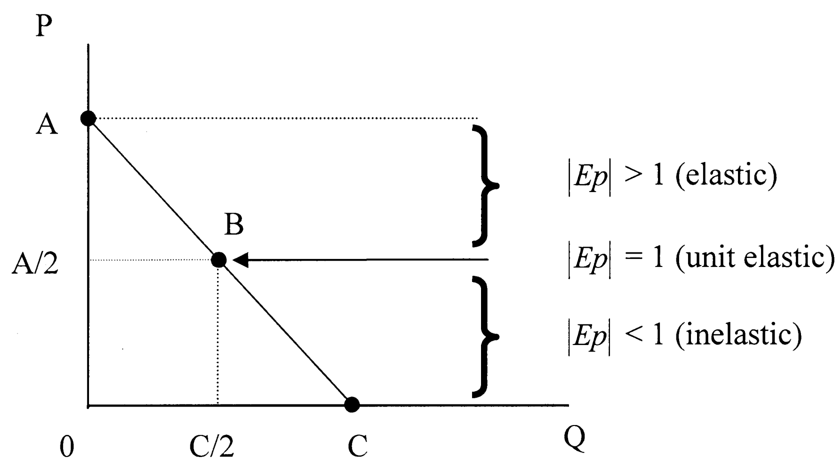
Table 8: Regression results for the Nerlove lagged-variable model, $Q_t = AP_t^b Y_t^c Q_{t-1}^d \varepsilon_i$ for U.S. crude oil from 1960 to 2003

period	Coefficients			P-value			adj. R^2
	Y	P	Q_{t-1}	Y	P	Q_{t-1}	
1961-2003	-0.014	-0.053	0.981	0.37	0	0	0.938
1961-1980	0.31186	-0.112	0.775	0.04	0	0	0.974
1962-1981	0.34299	-0.116	0.76	0.03	0	0	0.969
1963-1982	0.39203	-0.128	0.756	0.01	0	0	0.967
1964-1983	0.4438	-0.137	0.752	0	0	0	0.964
1965-1984	0.44628	-0.139	0.766	0	0	0	0.958
1966-1985	0.32285	-0.124	0.833	0.01	0	0	0.938
1967-1986	0.13013	-0.088	0.88	0.14	0	0	0.904
1968-1987	0.06967	-0.08	0.869	0.37	0	0	0.891
1969-1988	0.03804	-0.074	0.868	0.58	0	0	0.883
1970-1989	-0.00066	-0.07	0.851	0.99	0	0	0.876
1971-1990	-0.0569	-0.071	0.811	0.41	0	0	0.88
1972-1991	-0.13697	-0.075	0.761	0.08	0	0	0.89
1973-1992	-0.15777	-0.077	0.75	0.07	0	0	0.892
1974-1993	-0.16633	-0.073	0.754	0.09	0	0	0.881
1975-1994	-0.22376	-0.084	0.757	0.02	0	0	0.903
1976-1995	-0.37916	-0.109	0.692	0	0	0	0.947
1977-1996	-0.30307	-0.099	0.727	0.01	0	0	0.923
1978-1997	-0.1873	-0.078	0.759	0.07	0.003	0	0.904
1979-1998	-0.11764	-0.055	0.712	0.23	0.028	0	0.857
1980-1999	0.01423	-0.022	0.59	0.85	0.284	0	0.721
1981-2000	0.05342	-0.013	0.521	0.34	0.442	0.001	0.503
1982-2001	0.04558	-0.015	0.485	0.38	0.34	0.016	0.463
1983-2002	0.01066	-0.014	0.634	0.82	0.343	0.005	0.502
1984-2003	0.01142	-0.007	0.612	0.78	0.59	0.005	0.432

Short-term Price Elasticity of Demand

Price elasticity of demand, represented as Ep, is used to determine how sensitively consumers respond to a volume change as compared to a price change. It can be expressed as Ep = $\frac{\%\Delta Q^D}{\%\Delta P}$ (i.e. Ep = the rate of percentage change in quantity demanded compared to percentage change in price). In general, a fall in price is expected to increase quantity demanded; therefore, Ep is negative. When $|Ep|$ is larger than 1, the price elasticity of demand for this product is considered elastic. This means that the percentage change in quantity demanded is larger than the percentage change in price. When $|Ep|$ is equal to 1, the price elasticity of demand for this product is considered unit elastic. This means that the percentage change in quantity demanded is the same as the percentage change in price. When $|Ep|$ is smaller than 1, the price elasticity of demand for this product is considered inelastic. This means that the percentage change in quantity demanded is smaller than the percentage change in price (see Figure 6). The higher the price elasticity of demand, the more sensitive consumers will be to price changes. Higher price elasticity of demand implies that when the price of a product goes up, customers will purchase a significant less quantity of this product; when the price of a product goes down, customers will purchase a significant more quantity of this product (Forgionne & Ruppert, 1985). Automobiles, furniture, and transatlantic air travel are examples of highly price-elastic products. Lower price elasticity suggests that when the price of a product changes, customers reflect little changes to the quantity demanded of this product, for example, medical services, rental housing, food, and tobacco products (Nicholson, 1995). These products are considered inelastic goods.

Figure 6: Elastic, unit elastic, and inelastic demand along a linear demand curve



(Note. From "Managerial Economics Theory and Practice," by T. J. Webster, 2003, p. 164. Copyright 2003 by Academic Press.)

Given that demand elasticity is related to consumers' responsiveness to price changes, there is an interesting relationship between the price of the good and revenue received. When $|Ep| > 1$, a change in price causes a change in total revenue in the opposite direction. When $|Ep| < 1$, a change in price causes a change in total revenue in the same direction (Keat & Young, 1996). This relationship among price, price elasticity of demand, and total revenue explains why oil-exporting countries, such as OPEC, try to increase the price of crude oil. Since $|Ep| < 1$ for crude oil, increasing price increases total revenue to oil-exporting countries. A detail relationship is shown in Table 9.

Table 9 : The relationship between price elasticity and total revenue (TR)

Demand			
	Elastic	Unit elastic	Inelastic
P ↑	TR ↓	No change in TR	TR ↑
P ↑	TR ↑	No change in TR	TR ↓

(Note. From "Managerial Economics. Economics Tools for Today's Decision Markers, 2nd ed.," by R G., Keat & P. K. Y. Young, 1996. Copyright 1996 by A Simon & Shuster Company)

Cooper (2003) gave an example and explained how this adaptation of Nerlove's partial adjustment model works for the short-term price elasticity of demand and crude oil consumption.

If the long-term demand function for crude oil market is given by

$$D_{tL} = AP_t^{\alpha} Y_t^{\beta} \varepsilon_t \cdots\cdots\cdots\cdots (1)$$

and the gradual adjustment process is expressed as

$$\frac{D_{tL}}{D_{tS}} = \left[\frac{D_{tL}}{D_{t-1,S}}\right]^d \cdots\cdots\cdots\cdots \text{(2) where } 0 < d \leq 1, \text{ and}$$

d is coefficient of adjustment,

where

D_{tL} = long – term demand for crude oil in year t

D_{tS} = short – term demand for crude oil in year t

P = real price per barrel of crude oil in year t

Y = real GDP per capita in year t

e = random error term in D_{tL} for observation t

A, α, β, *d*, and ε are parameters to be estimated.

Cooper (2003) used the following example:

> Consider a hypothetical economy, which is seeking to reduce its consumption of crude oil. Suppose, for illustrative purposes, it has succeeded in reducing its oil consumption from 125 units in year t-1 to 110 units in year t, but, ideally, wants to reduce consumption to 100 units. Because of technical rigidities, this further reduction cannot be accomplished within a single period. Only a partial adjustment can be made each period, and the entire move to the new desired long-run level will be spread over several periods. (p. 7)

The arithmetical example above can be put into the equation (2) and becomes:

$$\frac{100}{110} = \left[\frac{100}{125}\right]^d \quad \text{where } 0.9091 = (0.8)^d\text{, from which } d = 0.4272$$

Solving for D_{tL} from equation (2)

$$\frac{D_{tL}}{D_{tS}} = \left[\frac{D_{tL}}{D_{t-1,S}}\right]^d \Rightarrow D_{tL} = \left(D_{tL}^d\right)\left(D_{t-1,S}^{-d}\right)\left(D_{tS}\right)$$

$$\frac{D_{tL}}{D_{tL}^d} = \frac{D_{tS}}{D_{t-1,S}^d} \Rightarrow \left(D_{tL}\right)^{1-d} = \left[\frac{D_{tS}}{D_{t-1,S}^d}\right] \Rightarrow D_{tL} = \left[\frac{D_{tS}}{\left(D_{t-1,S}\right)^d}\right]^{\frac{1}{1-d}}$$

Substituting into equation (1)

$$\left[\frac{D_{tS}}{\left(D_{t-1,S}\right)^d}\right]^{\frac{1}{1-d}} = AP_t^{\alpha} Y_t^{\beta} \varepsilon_t$$

$$\frac{D_{tS}}{(D_{t-1,S})^d} = A^{(1-d)} P_t^{\alpha(1-d)} Y_t^{\beta(1-d)} \varepsilon_t^{(1-d)} \Rightarrow D_{tS} = A^{(1-d)} P_t^{\alpha(1-d)} Y_t^{\beta(1-d)} D_{t-1,S}^d \varepsilon_t^{(1-d)}$$

which is in the same form as the modified Nerlove model $Q = AP_t^b Y_t^c Q_{t-1}^d \varepsilon_t$.

While in the multiple regression model derived from the modification of the Nerlove lagged-variable model, the equation can be transformed in terms of logarithmic form, $\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + \varepsilon_t$. The coefficient of the price term, represented as b, can be interpreted that a one unit decreases (or increases) in price, the quantity demanded will increase (or decrease) by b units. It confirmed that changes in a price will cause changes in quantity demanded, as expressed in movement along the demand curve. Therefore, the coefficient of the price term in this study can be used to interpret the short-term price elasticity of demand for U.S. crude oil. According to the estimates reported in academic literature, the short-term price elasticity of demand is somewhat distinct from the long-term price elasticity of demand. In other words, the longer the time period, the more likely consumers are to adjust quantities purchased to changes in price. Crude oil is no exception. It has been shown that the long-term price elasticity is generally more sensitive than the short-term price elasticity for crude oil. In this study, we focus on the short-term price elasticity of demand. Generally speaking, these estimates of short-term price elasticity vary according to different countries and different periods. For example, Brown & Philips (1989) and Cooper (2003) estimated the short-term price elasticity of demand for U.S. crude oil. Brown & Philips reported the short-term price elasticity of demand for U.S. economy to be -0.08 over the period from 1972 to 1988; on the other hand, Cooper presented a result of -0.06 for U.S. economy over the period from 1979 to 2000. Moreover, the price elasticity of demand for crude oil can be influenced by the availability of energy substitutes and market competitiveness, stated Hwang & Yang (2001). One of the results from their research showed that between the period of the 1950s and 1960s, demand for the individual producer was relatively elastic, while the industry demand was inelastic. After the Teheran Agreement in 1971, OPEC became an effective cartel and was able to exercise a considerable degree of monopoly power due to the fact that the demand curve changed over time. Recently, demand for the individual market has become relatively more inelastic. Consequently, OPEC could raise the price of crude oil even if consumption levels remain constant, or decrease.

In this study, we collected annual data from the U.S. crude oil market for the time period, 1960 to 2003, and applied these data into the modified Nerlove lagged-variable model. Considering that price elasticity of demand will vary according to different time periods, this model tests twenty-four 20-year periods (e.g. 1961-1980, 1962-1981,... and 1984-2003) from 1960 to 2003.[13] We therefore can compare these values to previous estimates and explain any deviations.

[13] We collected annual data from 1960 to 2003. Since the modified Nerlove model contains a lagged variable, the first period applied starts from 1961.

U.S. Crude Oil Market

The United States is the world's largest crude oil consuming country, accounting for about one-fourth of the total world crude oil consumption. Although energy is used more efficiently in this country than in many others, the price of energy resources is crucial to the health of the U.S. economy. According to EIA brochures, while the gasoline price was at an average of $1.56 per gallon in 2003, of which approximately 44% of the cost of a gallon was based on the cost of crude oil; 27% of the cost of that same gallon was comprised of the Federal, State, and local taxes; another 15% of the cost was made up of refining costs and refiners' profits; and the remaining 14% was accounted for by distribution, marketing, and retails mark-up costs. Since the cost of crude oil is the largest component of the retail price of gasoline, the rise in the price of crude oil directly affects the price of gasoline and results in an increase in the Federal, State, and local taxes. According to the data collected by EIA, an upward movement in the price of gasoline has occurred. In March of 2005, the average price of a gallon of gas reached over $2 throughout the entire United States. While this is not a unique phenomenon to such states as California and Hawaii, which have seen similar increases before, it represents for the rest of the nation a radical departure from the norm. This reflects an increase of more than $0.25 since January 2005. Transportation fuels therefore become more costly in daily expenditures. However, more interestingly, the number of sales of new vans, trucks, and Sport Utility Vehicles (SUVs) is still growing since the 1990s in the U.S. This may suggest that U.S. consumers generally accept the higher levels of fuel prices ("Crude Oil," 2004).

Moreover, due to the limitation of capital and availability of crude oil, refining capacity for crude oil becomes an important issue in the U.S. Since 1981, the number of U.S. refineries has dropped from 324 to 153 while the operating capacity has increased from 69% to 96%, according to the report from Garza (2004). This indicates that refineries' capacity creep[14] has been largely achieved through new technologies, and also reduces the pressure on U.S. consumers from the fluctuations in the price of crude oil.

Another important influence driven from the rise in the price of crude oil is energy efficiency. From 1990 to 1997, the annual percentage growth of U.S. crude oil consumption was 1.32%,[15] while the world demand growth rate was 1.37%.[16] In comparison, China, the second largest crude oil consuming country in the world had an annual growth rate of 7.91%.[17] Other countries in the Asian Pacific region were also experiencing great demand for crude oil. During this same period, while the United States economy was strong and the Asian Pacific region was booming, the world's demand for crude oil increased by 6.67 million barrels per day. Using this statistic, the consumption in the Asian Pacific region accounted for an increase of 5.9 million barrels per day,

---

[14] Capacity creep: A strategy of expanding and improving existing refineries.

[15] U.S crude oil consumption in 1990 was 16.99 million barrels/day; in 1997 was 18 62 million barrels/day. (Source: EIA, http://www.eia.doe.gov)

The annual rate of growth in U.S. crude oil consumption = $\sqrt[7]{\frac{18.62}{16.99}} - 1 \approx 1.32\%$

[16] World crude oil consumption in 1990 was 66 53 million barrels/day, in 1997 was 73.20 million barrels/day (Source: EIA, http://www.eia.doe.gov)

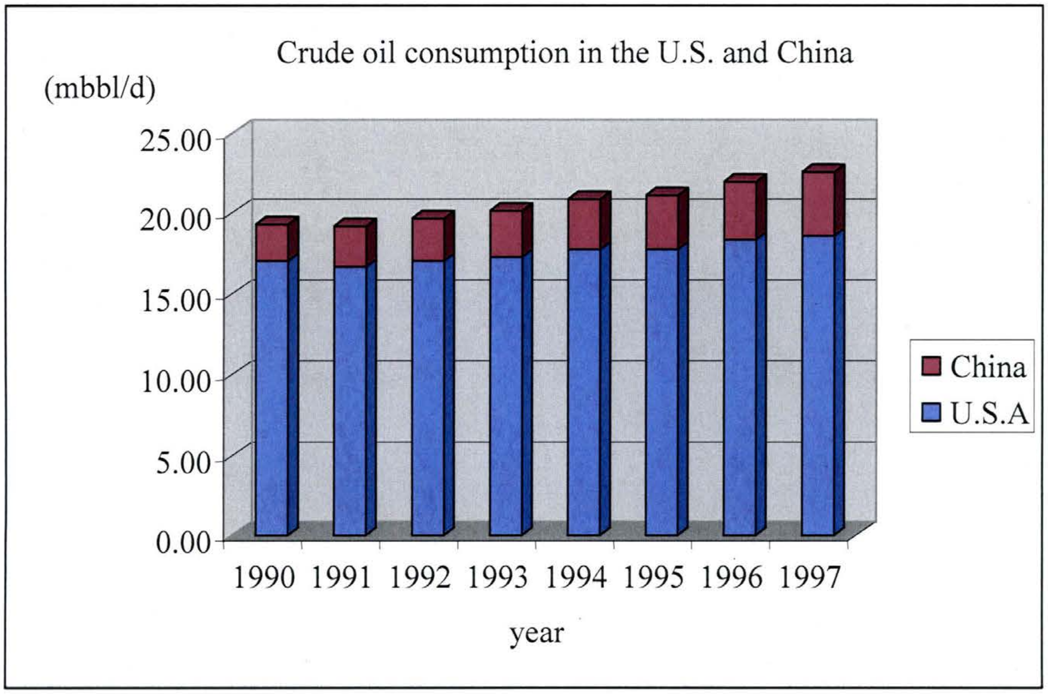
The annual rate of growth in world crude oil consumption = $\sqrt[7]{\frac{73.2}{66.53}} - 1 \approx 1.37\%$.

[17] China crude oil consumption in 1990 was 2 3 million barrels/day; in 1997 was 3.92 million barrels/day. (Source: EIA, http://www.eia.doe.gov)

The annual rate of growth in China crude oil consumption = $\sqrt[7]{\frac{3.92}{2.3}} - 1 \approx 7.91\%$.

resulting in a rapid rise in the price of crude oil, according to EIA. A comparison of consumption of crude oil between the U.S. and China from 1990 to 1997 is presented in Chart 7.

Chart 7: Crude oil consumption: the U.S. vs. China, from 1990 to 1997

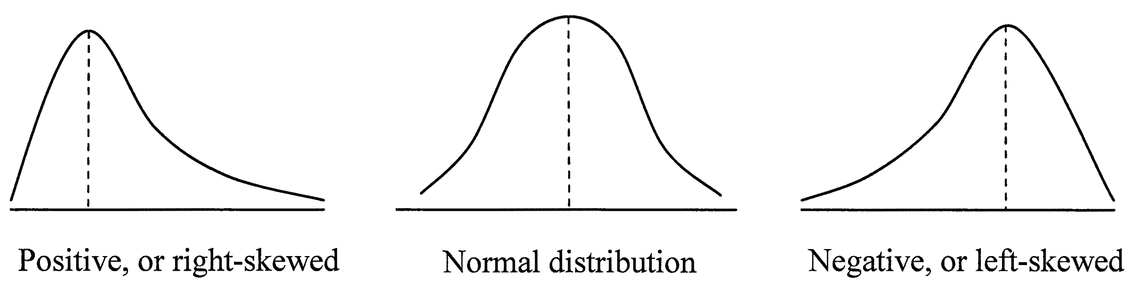


(Note. Data source from EIA, http://www.eia.doe.gov)

Because the United States has so many advantages, U.S. consumers have usually enjoyed a lower price of crude oil than that of other countries. According to the Energy Economics Newsletter ("Oil Price History and Analysis," 2002), the price of crude oil in the United States averaged approximately $19.61 per barrel in terms of 2000 dollar valuation during the post World War II era. Within the same period, the median price of crude oil in the United States was $15.25 per barrel in terms of 2000 dollar valuation. This means that more than half of the time during that period, the U.S. crude oil prices were below $15.25 per barrel. Considering the average price of crude oil during the

World War II and the median price of crude oil during the same period, the individual price of crude oil trended toward lower levels. By comparison, the world crude oil price averaged $21.12 per barrel, which was $1.51 higher than that of the U.S., while the median of the world crude oil price was $15.89, which was $0.74 higher than that of the U.S. This means that more than half of the time during that period, the world crude oil prices were below $15.89 per barrel. Although both of these two sets of data were positive, or right-skewed[18] (see Figure 7), it appears to be clear that U.S. consumers were experiencing a lower price of crude oil than the average world crude oil price.

Figure 7: Data sets in differing shape



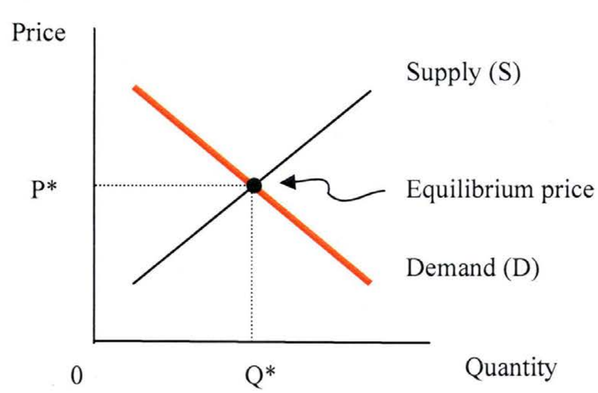
(Note. From "Statistics for Managers using Microsoft Excel, 4th ed.," by D. M. Levine, D. Stephan, T. C. Krehbiel, and M. L. Berenson, 2005, p. 121. Copyright 2005 by Pearson Education, Inc.)

[18] If the mean is greater than the median, the distribution is described as positive, or right-skewed. In this panel, there is a long tail on the right of the distribution and a distortion to the right that is caused by extremely large values. These extremely large values pull the mean upward so that the mean is greater than the median. Source: Statistics for Managers using Microsoft Excel, 4th ed

An Overview of U.S. Economic Activity

Based on economic theory, price is the reflection of supply and demand. By definition, demand refers to people's willingness to own an amount of a good and ability to buy that good at a given price; supply refers to people's willingness to sell an amount of a good at a given price. A number of factors can influence demand and supply. For instance, price of the good, income of consumers, substitutes for the good, complements of the good, and consumer tastes can cause a change in demand or the amount of demanded. Price of the good, cost of making the good, competitive supply, joint supply, and unexpected events can cause a change in supply or the amount supplied. In perfectly competitive markets, price is determined at the output level where quantity demanded is equal to quantity supplied. The point at the intersection of the supply curve and the demand curve is called equilibrium (see Figure 8). At this point, the amount of the good being supplied is exactly equal to the amount of the good being demanded. Under this circumstance, everyone is satisfied with the current economic condition.

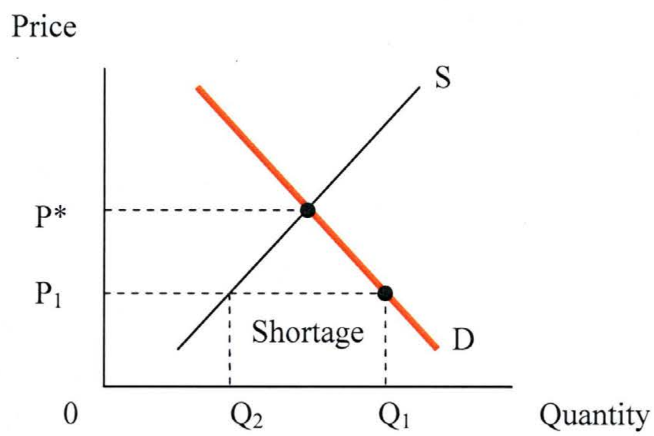
Figure 8: Market equilibrium

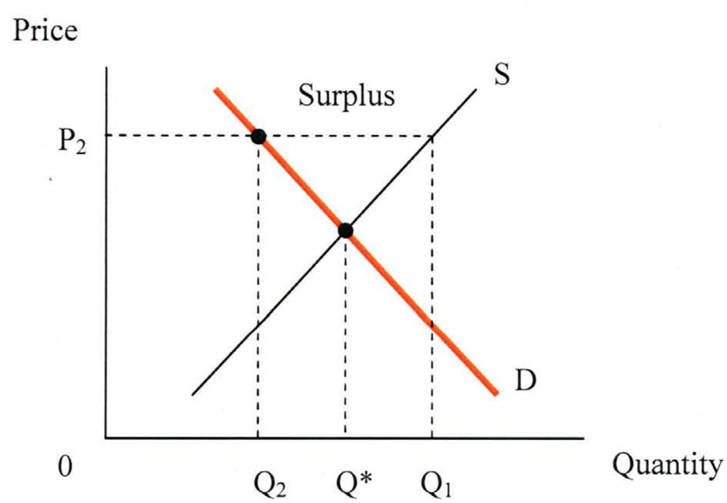


(Note. From "Managerial Economics and Business Strategy, 4th ed.," by M. R. Baye, 2003, p. 50. Copyright 2003 by McGraw-Hill/Irwin.)

Unfortunately, equilibrium can only be reached in theory. In most situations, the real market is usually in disequilibrium, which happens whenever the price is not equal to P* or quantity is not equal to Q* (see Figure 9).

Figure 9: Market adjustment to equilibrium





(Note. From "Managerial Economics: Analysis, Problems, Cases, 6th ed.," by L. J. Truett and D. B. Truett, 1998, p. 31. Copyright 1998 by South-Western College Publishing.)

According to Allen, Doherty, Weigelt, and Mansfield (2005), the actual price is close to the equilibrium price, since the basic factors will push the actual price toward the equilibrium price. If the actual price is smaller than the equilibrium price, there will be an upward pressure on price. A change in price will cause a movement along the demand curve. Shown in the Figure 10, an increase in price, form P_1 to P_2, results in the fall in the quantity demanded, from Q_1 to Q_2. Demand curve shifts when a change occurs in income, substitutes, complements, or consumer taste. Shown in Figure 11, the demand curve shift from D to D_1 results in an increase in price from P* to P_1; on the other hand, demand curve shift form D to D_2 results in a decrease in price from P* to P_2.

Figure 10: Movement along in demand curve

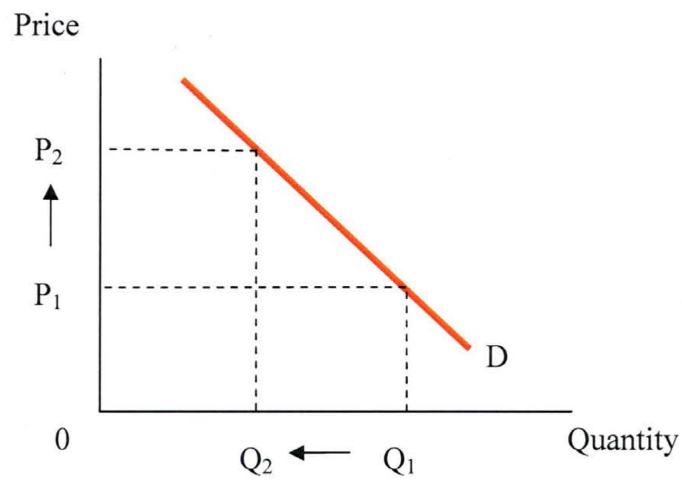
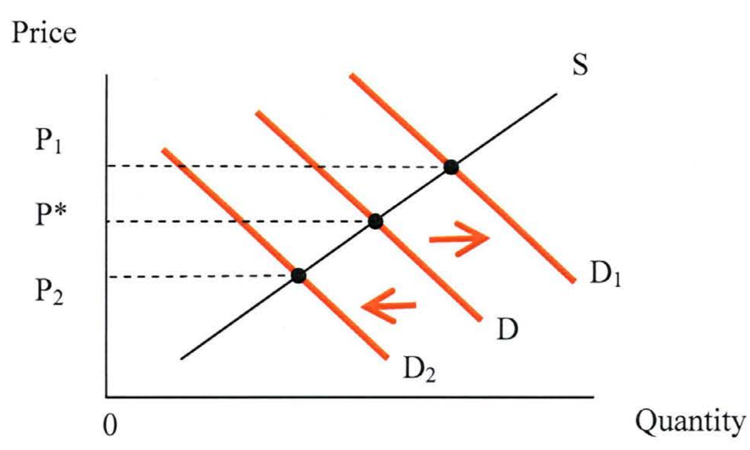


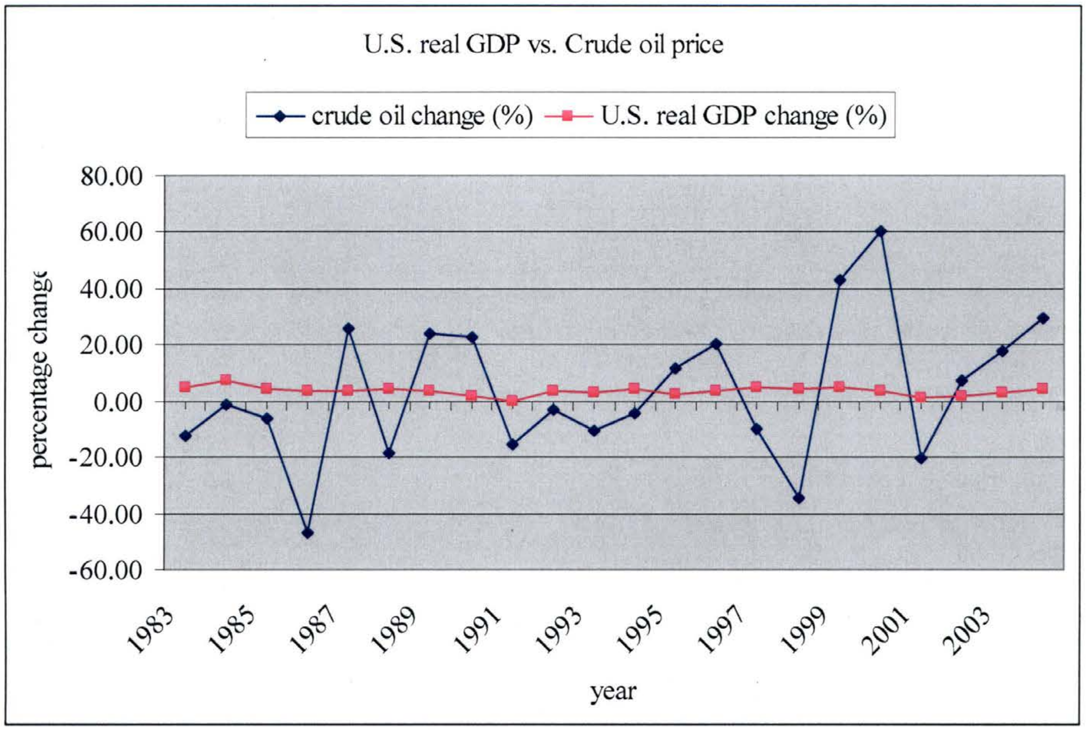
Figure 11: Shift in demand curve

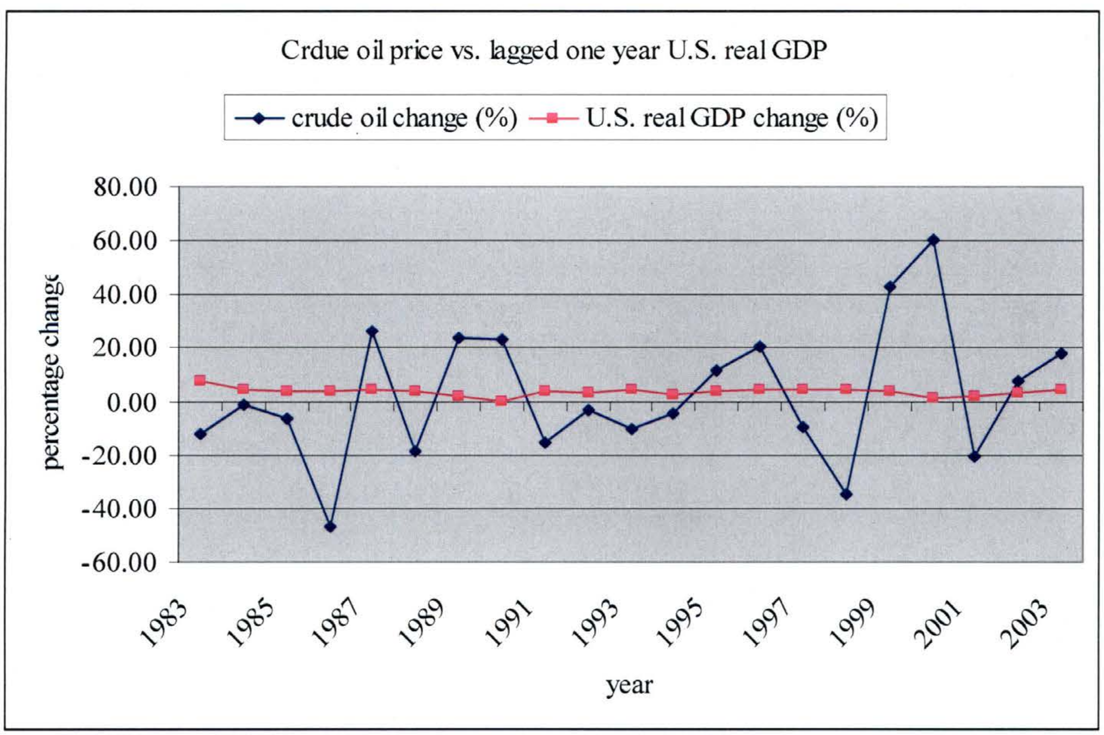


In the opposite situation, a change in price will cause a movement along the supply curve. An increase in price results in the fall of the quantity supplied. Supply curve shifts when a change in cost, competition, joint supply, or unexpected events occur. In the present environment, crude oil is considered the most important energy source we have. Most industries and individuals depend on it on a daily basis. Since crude oil is a non-renewable resource and its reserves are limited, supply for crude oil is controlled by oil-exporting countries.

The United States accounts for one-fourth of total crude oil consumption. It exerts enormous influence on the price of world crude oil. According to the daily newsletter ("Stocks Struggle," 2005), Alcoa Inc. shares struggled because of the high crude oil price. The company planned to cut 5% of its employees in order to reflect the increased costs. Consequently, the unemployment rate will increase and the condition of the economy will become worse as a result. On the other hand, positive effects on economic activity are expected as crude oil prices fall. However, research conducted by Balks, Brown, and Yücel (2002) suggested that there appeared to be an asymmetrical relationship between crude oil prices and aggregate U.S. economic activity. There was a disproportionate effect on the U.S. economy while the U.S. was experiencing crude oil price declines and increases. In general, falling crude oil prices boost economic activity and rising crude oil prices result in economic recession. Although the U.S. economy was expanding during the last two decades, the movements of crude oil prices have different impacts on the aggregate U.S. economy. Observing U.S. historical data from 1983 to 2004, we find that the U.S. real GDP response to crude oil price movements seems commensurate with this asymmetry (see Chart 8).

Chart 8: percentage change in U.S. real GDP and crude oil price





(Note. Data source from Economagic database, http://economagic.com)

In addition, Brown et al. (2003) investigated such a question in their paper, "Why doesn't the economy respond as favorably to falling oil prices as it responds unfavorably to rising oil prices" (p. 2)? They concluded that rising oil prices resulted in real GDP losses because of a classic supply-side effect. This effect indicated that the total input to production has been reduced, quantity demanded decreased as a result of an increased price level, and a monetary policy raises interest rates in response. A potential outcome of reducing output, reducing sales, and increasing financial stress creates uncertainty within individual firms. These influences retard companies' investment decisions and slow economic expansion. Under such an environment, investors may lose their confidence in these companies and therefore push major U.S. stocks lower. Consequently, the effects of rising oil prices are very strong. The oil price decline during the 1980s and 1990s did not help U.S. economic activity as much as rising oil prices hurt U.S. economic activity. Although falling oil prices can increase production output and consumers' purchasing power, monetary policy may still be held constant and contribute to an asymmetry. Moreover, uncertainty about future oil prices will weaken economic activity whether oil prices are rising or falling. In other words, positive effects of falling oil prices are offset by the negative effects of rising oil prices. Therefore, the change in oil prices has an asymmetrical response to U.S. economic activity.

CHAPTER IV

DATA AND METHODOLOGY

Concept and Hypotheses

Model concept

$$Q_t = AP_t^{b}Y_t^{c}Q_{t-1}^{d}E/G^{e}_{t}\varepsilon_t$$

In this study, a modified form of the Nerlove lagged-variable model is used to predict U.S. demand for crude oil and to estimate the short-term price elasticity of demand for U.S. crude oil. The model contains one dependent variable and four independent variables. The dependent variable is U.S. per-capita demand for crude oil. The independent variables are the real price of U.S. crude oil, U.S. per-capita real GDP, U.S. per-capita demand for crude oil lagged one year, and U.S. energy-consumption-to-GDP ratio. The exponent of the price term in the model is a measure of short-term price elasticity of demand for U.S. crude oil. In order to overcome violations to the homoscedasticity assumption, a logarithmic transformation is used in this study to change a nonlinear model, $Q_t = AP_t^{b}Y_t^{c}Q_{t-1}^{d}E/G^{e}_{t}\varepsilon_t$, into a linear model, $\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + e\ln E/G_t + \varepsilon_t$ (Levine et al., 2005).

The annual data for this study were collected during the period between 1960 and 2003. The model was estimated for the entire period from 1960 to 2003 and for each of twenty-four 20-year periods (e.g., 1961-1980, 1962-1981, 1963-1982, …and 1984-2003) in the 44-year interval. Estimating the model's parameters in this manner shows that the crude oil market was changing throughout the 1960-2003 time period and provides a series of 24 estimates of short-term price elasticity of demand for crude oil over the interval since the exponent of the price term for each of these 20-year periods measures short-term price elasticity of demand for crude oil in the U.S.

The data used in estimating this modified form of the Nerlove lagged-variable model come from a variety of sources. The data on U.S. crude oil consumption are obtained from the U.S. Department of Energy, Energy Information Administration (http://www.eia.doe.gov). The data on U.S. real crude oil prices come from InflationData.com (http://inflationdata.com/Inflation/default.asp) and are adjusted for inflation using 2000 as the base year. The data on both U.S. population and real GDP (base year = 2000) are from the Economagic database (http://economagic.com). The data on U.S. energy-consumption-to-GDP ratio are obtained from the Federal Reserve Bank of Dallas (http://www.dallasfed.org). U.S. real GDP and U.S. demand for crude oil are divided by U.S. population to create two series, U.S. per-capita real GDP and U.S. per-capita demand for crude oil, to avoid bias resulting from increases in population.

The multiplicative model with four independent variables can be expressed as

$$Q_t = AP_t^{b}Y_t^{c}Q_{t-1}^{d}E/G_t^{e}\varepsilon_t$$

A logarithmic transformation yields a form of the model that is linear in logarithms and much easier to estimate.

$$\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + e\ln E/G_t + \varepsilon_t$$

The parameters and variables in the model have the following meanings.

Q_t = U.S. demand for the crude oil market

A = Q_t intercept

b = slope of Q_t with variable P_t holding variables Y_t, Q_{t-1}, and E/G_t constant

c = slope of Q_t with variable Y_t holding variables P_t, Q_{t-1}, and E/G_t constant

d = slope of Q_t with variable Q_{t-1} holding variables P_t, Y_t, and E/G_t constant

e = slope of Q_t with variable E/G_t holding variables P_t, Y_t, and Q_{t-1} constant

ε_t = random error in Q_t for observation t

A, b, c, d, and e are parameters to be estimated.

Data Description – a natural logarithm transformation for all of the following variables

The dependent variable:

Q_t : U.S. per-capita consumption of crude oil in year t

The independent variables:

P_t : real price per barrel of U.S. crude oil in year t

Y_t : annual U.S. per-capita real GDP in year t

Q_{t-1} : U.S. per-capita consumption of crude oil in year t-1

E/G_t: U.S. energy-consumption-to-GDP ratio

ε_t : random error in Q_t for observation t

Hypotheses

A modified Nerlove lagged-variable model expressed as

$$Q_t = AP_t^bY_t^cQ_{t-1}^dE/G^e_t\varepsilon_t$$

and transformed logarithmically as

$$\ln Q_t = \ln A + b\ln P_t + c\ln Y_t + d\ln Q_{t-1} + e\ln E/G_t + \varepsilon_t$$

is estimated using U.S. market data for these variables for the time period, 1960 to 2003. The theoretical model described above postulates that U.S. demand for world crude oil can be explained by four independent variables -- the real price of crude oil, U.S. per-capita real GDP, U.S. per-capita demand for crude oil lagged by one year, and U.S. energy-consumption-to-GDP ratio. In non-technical language, this model says that changes in the amount of crude oil consumed annually in the U.S. can be explained by changes that are occurring simultaneously in the real price of crude oil, U.S. per-capita real GDP, U.S. per-capita demand for crude oil in the previous year, and U.S. energy-consumption-to-GDP ratio.

In this multiple regression model, the slope b represents the change in the mean of Q_t per unit change in P_t, holding constant the effects of other independent variables. The slope c represents the change in the mean of Q_t per unit change in Y_t, holding constant the effects of other independent variables. The slope d represents the change in the mean of Q_t per unit change in Q_{t-1}, holding constant the effects of other independent variables. The slope e represents the change in the mean of Q_t per unit change in E/G_t, holding constant the effects of other independent variables In this regression model, the slopes (b, c, d, and e) are referred to as net regression coefficients.

In order to determine whether there is a significant relationship between the dependent variable and the set of explanatory variables, standard statistical tests will be applied. Additionally, since the model yields estimates of the short-term price elasticity of demand for crude oil, these estimates will be compared with results from other empirical studies of short-term price elasticity of demand for crude oil. If price elasticity results of this study are consistent with findings by other researchers in unrelated studies, then additional support is provided for the modified Nerlove lagged-variable model estimated in this study.

The null hypothesis (H_o) and alternative hypothesis (H_1) are as follows:

H_o: b = c = d = e = 0, none of the variables is significant

(i.e., there is no relationship between the dependent variable and the explanatory variables)

H_1: At least one variable is significant

(i.e., a relationship exists between the dependent variable and at least one of the explanatory variables)

The null hypothesis is tested based on the overall F statistic at a 0.05 level of significance,[19] or a confidence level[20] of 95%. The critical value of the F distribution, which is determined by the level of significance and degrees of freedom, will be compared with the computed F statistic, which is based on the given sample results. If the computed F statistic is greater than the critical value of the F distribution, the null hypothesis is rejected; if the computed F statistic is smaller than or equal to the critical value of the F distribution, the null hypothesis is not rejected. However, if the null

---

[19] Level of significance is the probability of committing a Type I error, denoted by α. (A Type I error occurs if H_0 is rejected when it is true and should not be rejected.)

[20] Confidence level is the complement ($1-\alpha$) of the probability of a Type I error multiplied by 100 %.

hypothesis is rejected, residual analysis will be applied to evaluate whether the regression model is an appropriate model. Other testing approaches such as the adjusted R^2 figure and the p-value are also used in this study to examine the results of the multiple regression model (Levine et al., 2005).

Hypotheses Testing

In order to determine whether there is a significant relationship between the dependent variable and the set of explanatory variables, hypothesis testing has been used to observe the results from the sample data. This testing is designed so that acceptance or rejection of the null hypothesis can be determined by evidence from the sample data. When the null hypothesis is rejected, it means that there is statistical proof that the alternative hypothesis is correct. In other words, acceptance of the alternative hypothesis represents rejection of the null hypothesis at a specified level of significance because there is sufficient evidence from the sample information. However, when the null hypothesis is not rejected, it only suggests that there is no proof that the alternative hypothesis is correct (Levine et al., 2005).

Hypotheses

$H_o : b = c = d = e = 0$, none of the variables is significant

H_1 : At least one variable is significant

F-test

The null hypothesis is tested based on the overall F statistic (see Table 10) at a 0.05 level of significance (i.e., the confidence level is 95%).

The critical values of the F distribution with 4 and 15 degrees of freedom (the 20-year period), and with 4 and 38 degrees of freedom (the entire period from 1960-2003) obtained from Appendix A are approximately 3.06 and 2.63. If the F statistic given in the analysis of variance (ANOVA) summary table is greater than the critical value F shown above, the null hypothesis is rejected; otherwise, the null hypothesis is not rejected.

Table 10: ANOVA summary table for a multiple regression model with k explanatory variables

Source	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F
Regression	K	SSR	$MSR = \frac{SSR}{k}$	$F = \frac{MSR}{MSE}$
Residual	n-k-1	SSE	$MSE = \frac{SSE}{n-k-1}$	
Total	n-1	SST		

(Note From "Statistics for Managers using Microsoft Excel, 4th ed.," by D. M. Levine, D. Stephan, T. C. Krehbiel, and M. L. Berenson, 2005, p. 587 Copyright 2005 by Pearson Education, Inc.)

In the F test for the entire multiple regression model, the F statistic is equal to the regression mean square (MSR) divided by the error mean square (MSE).

$$F = \frac{MSR}{MSE}$$

Where

n = number of observations

k = number of explanatory variables in the regression model

SSR = explained variation or regression sum of squares

SSE = unexplained variation or error sum of squares

SST = the total sum of squares, which is equal to the sum of SSR and SSE

MSR = the regression mean square, which is equal to SSR divided by k

MSE = the error mean square, which is equal to SSE divided by n-k-1

According to the sample data for the whole period from 1960 to 2003 and the 20-year period, the decision rule (see Figure 12 and 13) is the following:

Reject H_0 at the α level of significance if $F > F_{u(k, n-k-1)}$; otherwise, do not reject H_0.

Figure 12: F test at a 0.05 level of significance with 4 and 15 degrees of freedom

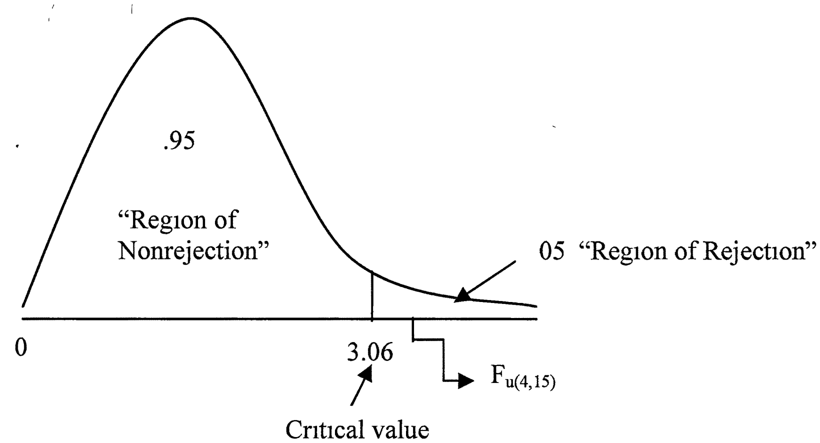
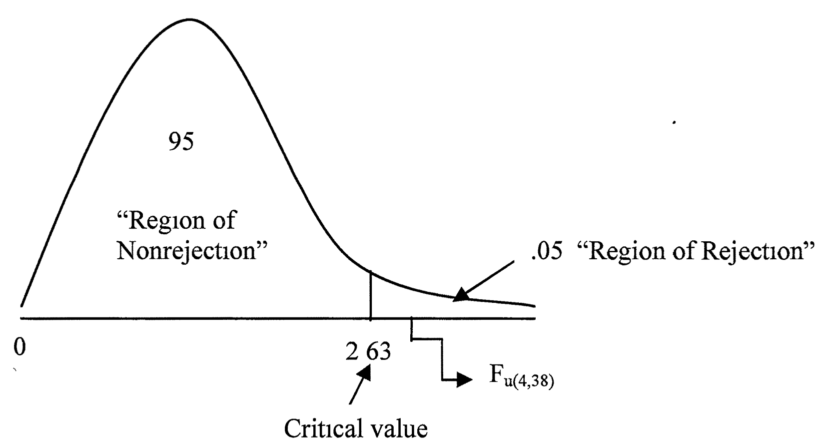


Figure 13: F test at a 0.05 level of significance with 4 and 38 degrees of freedom



(Note. Figure 11 &12 From "Statistics for Managers using Microsoft Excel, 4th ed ," by D. M Levine, D. Stephan, T C. Krehbiel, and M L. Berenson, 2005, p. 588 Copyright 2005 by Pearson Education, Inc.)

The adjusted R^2

The adjusted R^2, suggested by most statisticians, was obtained from the coefficient of multiple determination, represented as R^2. The adjusted R^2 adjusts both the number of explanatory variables in the model and the sample size. It reflects the percentage of variation in the dependent variable that can be explained by variation in the independent variables in the multiple regression model (Levine et al., 2005).

The adjusted R^2 can be defined as follows:

$$R^2_{Y\,12\,k} = \frac{SSR}{SST}$$

$$\text{adjusted } R^2 = 1 - \left[\left(1 - R^2_{Y\,12\,k}\right)\frac{n-1}{n-k-1}\right]$$

where

Y is the dependent variable.
(In this study, Y represents Q_t, which is U.S. demand for crude oil)

k is the number of explanatory variables in the regression equation.
(In this study, k = 4.)

Other symbols are defined the same as Table 10.

The p-value

The p-value approach is referred to as the observed level of significance (α), which is the smallest level at which H_0 can be rejected for a given set of data. This approach is used to test whether or not the individual variable is significant. If the p-value is greater than α, the coefficient of that variable is insignificant; if the p-value is smaller than α, the coefficient of that variable is statistically different from zero (Levine et al., 2005).

Regression Results and Analysis

Regression Results

The regression results of the modified Nerlove lagged-variable model for U.S. crude oil from 1960 to 2003 and the twenty-four 20-year periods are presented in Table 11. The slope in this multiple regression model is shown in the first line of the coefficients column. The p-value is presented in the second line, shown in the parenthesis. The adjusted R^2 and F statistic are also detailed in the table.

Table 11: Regression results of the modified Nerlove lagged-variable model for U.S. crude oil from 1960 to 2003

$Q = f(Y, P, Q_{t-1}, E/G)$

Period			Coefficients			adj. R^2	F statistic
	Constant	ln Y	ln P *	ln Q_{t-1}	ln E/G		
1961-2003	-6.370	0.339	-0.026	0.765	0.495	0.950	199.212
		(0 004)	*(0 048)*	*(0.000)*	*(0 000)*		
1961-1980	-5.361	0.392	-0.085	0.725	0.206	0.972	167.800
		(0.112)	*(0.204)*	*(0.001)*	*(0.667)*		
1962-1981	-5.122	0.396	-0.099	0.733	0.162	0.968	143.297
		(0 063)	*(0 056)*	*(0 000)*	*(0.691)*		
1963-1982	-6.129	0.468	-0.105	0.718	0.216	0.966	133.977
		(0.031)	*(0 037)*	*(0 000)*	*(0 580)*		
1964-1983	-8.504	0.615	-0.102	0.664	0.371	0.965	130.082
		(0.010)	*(0 025)*	*(0.000)*	*(0 323)*		
1965-1984	-10.315	0.715	-0.094	0.639	0.516	0.960	114.882
		(0 006)	*(0 029)*	*(0 000)*	*(0 192)*		
1966-1985	-13.775	0.861	-0.058	0.602	0.875	0.950	91.177
		(0.005)	*(0.122)*	*(0.000)*	*(0.042)*		
1967-1986	-16.093	0.981	-0.041	0.569	1.074	0.944	81.432
		(0.001)	*(0 055)*	*(0.000)*	*(0 003)*		
1968-1987	-20.196	1.226	-0.026	0.523	1.373	0.944	80.373
		(0.000)	*(0.181)*	*(0.000)*	*(0.001)*		

The p-value is in the second line, shown in the parenthesis.

* The coefficient of the price term in the model is a measure of short-term price elasticity of demand.

Table 11: Regression results of the modified Nerlove lagged-variable model for U.S. crude oil from 1960 to 2003 (continued)

Period	Coefficients					adj. R^2	F statistic
	Constant	ln Y	ln P *	ln Q_{t-1}	ln E/G		
1969-1988	-20.748	1.254	-0.019	0.526	1.425	0.940	74.941
		(0.000)	*(0.316)*	*(0.000)*	*(0.001)*		
1970-1989	-18.917	1.120	-0.017	0.531	1.327	0.925	59.684
		(0.004)	*(0.421)*	*(0.000)*	*(0.004)*		
1971-1990	-16.269	0.932	-0.023	0.531	1.176	0.916	52.943
		(0.019)	*(0.320)*	*(0.001)*	*(0.013)*		
1972-1991	-13.873	0.751	-0.030	0.515	1.054	0.916	52.662
		(0 061)	*(0 225)*	*(0.002)*	*(0 028)*		
1973-1992	-12.873	0.675	-0.035	0.510	1.006	0.915	52.112
		(0 085)	*(0 184)*	*(0.003)*	*(0.035)*		
1974-1993	-14.281	0.741	-0.034	0.467	1.137	0.909	48.287
		(0.071)	*(0.191)*	*(0.008)*	*(0.028)*		
1975-1994	-14.191	0.711	-0.043	0.460	1.183	0.937	72.217
		(0.035)	*(0.056)*	*(0.002)*	*(0.007)*		
1976-1995	-6.427	0.198	-0.079	0.522	0.709	0.958	110.139
		(0 462)	*(0.000)*	*(0.000)*	*(0.039)*		
1977-1996	-10.626	0.427	-0.074	0.420	1.041	0.953	98.153
		(0.083)	*(0.000)*	*(0 002)*	*(0.004)*		
1978-1997	-9.652	0.370	-0.076	0.437	0.967	0.937	71.415
		(0.081)	*(0.000)*	*(0.003)*	*(0.008)*		
1979-1998	-7.610	0.269	-0.067	0.476	0.772	0.878	35.313
		(0 235)	*(0.008)*	*(0.004)*	*(0.071)*		
1980-1999	-2.208	0.062	-0.025	0.568	0.103	0.704	12.279
		(0.800)	*(0.328)*	*(0.001)*	*(0.837)*		
1981-2000	-0.926	0.009	-0.012	0.534	-0.082	0.472	5.240
		(0.967)	*(0.501)*	*(0.003)*	*(0.842)*		
1982-2001	-1.952	0.053	-0.015	0.485	0.014	0.428	4.550
		(0.796)	*(0.356)*	*(0 020)*	*(0.969)*		
1983-2002	-2.156	0.073	-0.012	0.638	0.101	0.475	5.290
		(0 650)	*(0.417)*	*(0.006)*	*(0.684)*		
1984-2003	-1.376	0.025	-0.007	0.610	0.020	0.394	4.092
		(0.854)	*(0.662)*	*(0.007)*	*(0.916)*		

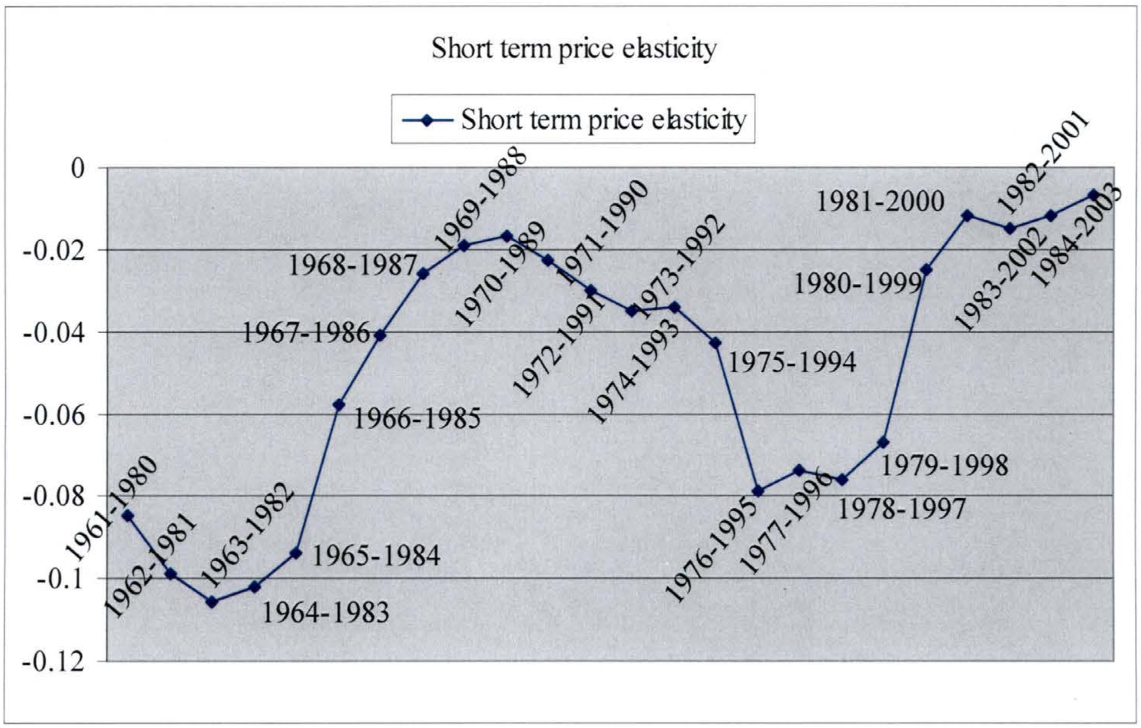
The p-value is in the second line, shown in the parenthesis.

* The coefficient of the price term in the model is a measure of short-term price elasticity of demand.

** Raw data are presented in Appendix B.

The estimated short-term price elasticity of demand is represented as the coefficient of the price term. Chart 9 shows the results of the short-term price elasticity of demand for the twenty-four 20-year periods. All of the estimates are negative and small as expected.

Chart 9: Short-term price elasticity of demand for twenty-four 20-year periods



Regression Analysis

According to the regression results shown in Table 11, the overall F statistic (199.212) is larger than the critical value of the F distribution[21] with 4 and 38 degrees of freedom (2.63) from 1960 to 2003; therefore, H_0 is rejected. For the twenty-four 20-year periods, all of the overall F statistics are larger than the critical value of the F distribution with 4 and 15 degrees of freedom (3.06); therefore, we reject H_0 and say that there is sufficient evidence from the sample data showing that the alternative hypothesis is correct.

The adjusted R^2 suggests that the model fits the data for the whole period, from 1960 to 2003. Caution must be exercised when using models to predict outcomes, but statistical tests suggest that the modified Nerlove lagged-variable model postulated and estimated in this study describes the relationship between U.S. demand for crude oil and the four independent variables -- the real price of U.S. crude oil, U.S. per-capita real GDP, U.S. per-capita demand for crude oil lagged one year, and U.S. energy-consumption-to-GDP ratio – and can be used to identify the relationship between price and quantity demanded of crude oil in the U.S. However, for these twenty-four 20-year periods, the adjusted R^2 becomes smaller after the period between 1980 and 1999. After considering the data in 2000, 2001, 2002, and 2003, the adjusted R^2 drops and becomes less than 0.5. This suggests that less than 50% of the variation in the U.S. crude oil demand can be explained by the variations in the real GDP per-capita, real crude oil

[21] The overall F test is based on the level of significance, $\alpha = 0.05$.

price, U.S. crude oil demand lagged one year, and U.S. energy-consumption-to-GDP ratio.

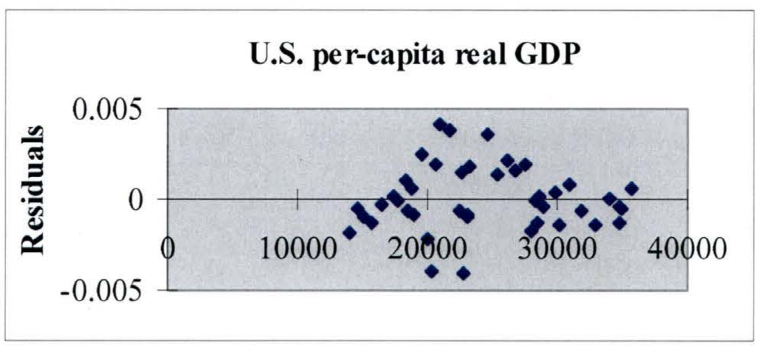
Based on the p-value approach, α = 0.05, the coefficients for all of the variable terms except the distributed lag term since the period between 1980 and 1999 are not statistically different from zero. This suggests that there is no relationship between the dependent variable (U.S. demand for crude oil) and those independent variables (real GDP per capita, real crude oil price, and U.S. energy-consumption-to-GDP ratio) in the data period from 1980 to 1999, 1981 to 2000, 1982 to 2001, 1983 to 2002, and 1984 to 2003. Apparently economic events, economic or non-economic shocks to the economy, or aberrations in consumer behavior, occurred during these periods that were not captured by the variables in the model, and these specific periods, especially the time period after 2000, require further study. Interestingly, the coefficient of the price term is the only insignificant variable among all the independent variables from the period between 1967 and 1986 to the period between 1971 and 1990, even though the adjusted R^2 and the overall F statistic show that the model fits the data very well.

As expected, the estimated short-term price elasticities of demand, which are between -0.105 and -0.07, suggest that crude oil demand is highly price-inelastic. Among these figures, only between -0.105 (1963-1982) and -0.094 (1965-1984), and between -0.079 (1976-1995) and -0.067 (1979-1998) are statistically significant. Those are very close to the estimate for the U.S. crude oil market reported by Brown & Philips (1989). They estimated the short-term price elasticity of demand for U.S. crude oil to be -0.08 over the period between 1972 and 1988.

Residual Analysis

Residual analysis is a graphical approach developed to evaluate a regression model that has been fitted to data. It is usually used after the null hypothesis is rejected. In this study, we want to evaluate whether the modification of the Nerlove lagged-variable model is useful for predicting purposes. The residual, represented as e_i and often called estimated error value, is defined as the difference between the observed variable and predicted variable. If the fitted model is appropriate for the data, there will be no apparent pattern in the residual plot (Levine et al., 2005). Residual plots for the modified form of the Nerlove lagged-variable model are observed in Chart 10. The sample data used for residual plots are original values of the model from 1960 to 2003.

Chart 10: Residual plots of U.S. demand for crude oil



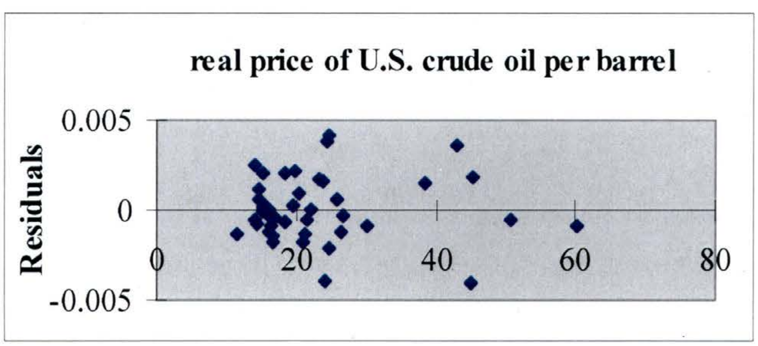
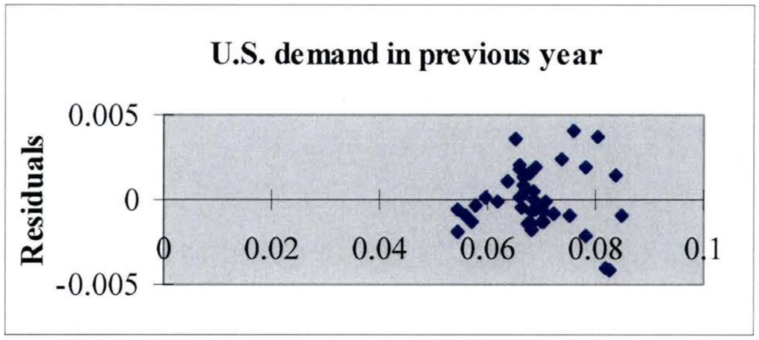
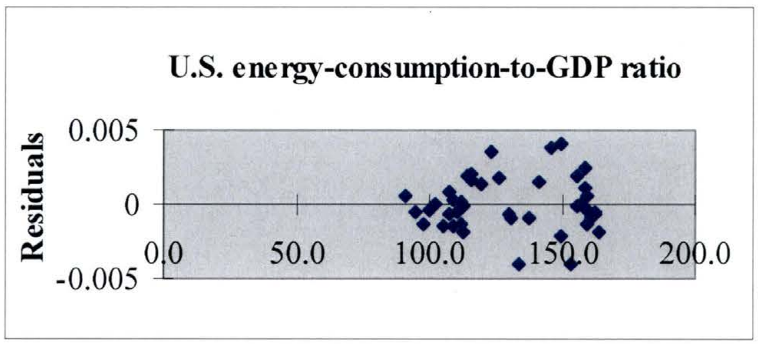


Chart 11: Residual plots of U.S. demand for crude oil (continued)





From Chart 10, there appears to be very little or no pattern in the relationship between the residuals and the values of P_t, Y_t, Q_{t-1}, and E/G_t. This indicates that the multiple regression model should be used with caution, but is appropriate for predicting U.S. demand for crude oil (Q_t).

In summary, the modified form of the Nerlove lagged-variable model has at least one of the explanatory variables significant in all of the periods, and this model fits the data well in most periods. Some exceptions occur because factors outside the model, such as uncertainty in the quantity supplied and political affairs, come into play.

CHAPTER V

CONCLUSIONS

Summary of the Thesis

This study provided a combination of factors that influence demand and price in the world crude oil market and estimated a modified form of the Nerlove lagged-variable model by using U.S. crude oil market data. This paper developed a demand function that showed how the real price of U.S. crude oil, per-capita real U.S. GDP, per-capita U.S. demand for crude oil lagged one year, and U.S. energy-consumption-to-GDP ratio affect U.S. demand for world crude oil in a given year. This model was used to determine the short-term price elasticity of demand which explained the responsiveness of quantity demanded to a change in price. By covering various different periods from 1961 to 2003, the estimated short-term price elasticities of demand varied between -0.105 and -0.007. The trend of the result shows that the estimates of price elasticity of demand change to highly price-inelastic in the recent periods as shown in Chart 9; however, these figures were not statistically different from zero. In the most of the periods, the results of regression showed that at least 90% of variation in the dependent variable data can be explained by variation in the independent variables in this modified model. During the data periods from 1981 to 2000, 1982 to 2001, 1983 to 2002, and 1984 to 2003, less than 50% of data could be explained by this modified model.

Recommendations for Future Research

Given that crude oil is a non-renewable resource and has been used widely as a major energy source, it plays an important role in the economic activity. A number of analysts and economists have investigated the relationship between demand and price for crude oil and have offered some possible explanations for such a relationship. The most common model that has been used to test this relationship is the Nerlove lagged-variable model, $Q_t = AP_t^bY_t^cQ_{t-1}^d\varepsilon_t$. In this study, we found that the ratio between energy consumption and GDP has declined in the U.S. since the 1970s and considered it an independent variable. This additional variable helps solve the problem in negative coefficients of real per capita GDP terms while only using the model above alone. However, the model cannot fit the data well after the period from 1981 to 2000, and the coefficients of price term are not statistically significant. To overcome this problem, this study suggests a few more considerations, including supply capacity, trading activity, alternative energy sources, and government policy. Such studies[22] have shown that these factors have influenced the crude oil market. For example, a wide variety of businesses, including oil refiners, airlines companies, oil retailers, and other major consumers of fuel oil participate in trading activity in an effort to more effectively manage risk. Activities in the market for crude oil futures contracts may influence price.

Considering the dramatic expansion of the economies of developing countries such as China and India (as discussed in the earlier chapter), increased demand for crude oil can be expected. Therefore, a number of scientists have investigated alternative energy sources to replace or supplement crude oil in order to avoid the crisis that would

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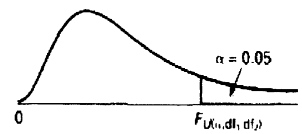
[22] Studies such as Pursell (2000), Soligo & Jaffe (2004), Yetiv (2004), and Chinn, LeBlanc, and Coibion (2005).

result from crude oil shortages. If such alternative resources are discovered, crude oil as an energy source will be less important and demand for this good will decrease as a result. Discovery of new sources of energy will provide opportunities for further studies in the area of energy demand.

Critical Values of *F*

For a particular combination of numerator and denominator degrees of freedom, entry represents the critical values of F corresponding to a specified upper-tail area (α).



Denominator df_2	NUMERATOR, df_1: 1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.40	199.50	215.70	224.60	230.20	234.00	236.80	238.90	240.50	241.90	243.90	245.90	248.00	249.10	250.10	251.10	252.20	253.30	254.30
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.91	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

(Source: Statistics for Managers Using Microsoft Excel, 4th ed., p. 847.)

APPENDIX B – RAW DATA

annual	U S demand (thousands/b)	real GDP in 2000 dollars(Billions of Dollars)	real price adjusted in 2000 dollars ($/b)	previous demand (thousand/b)	Energy/GDP ratio (base year = 2000)	U S population
	D	Y	P	D_{t-1}	E/G	
1960	9800	2,501 8			162 3	179972000
1961	9,980	2,560 0	16 644	9,800	163 6	182976000
1962	10,400	2,715 2	16 536	9,980	162 3	185739000
1963	10,740	2,834 0	16 262	10,400	161 0	188434000
1964	11,020	2,998 6	15 998	10,740	159 7	191085000
1965	11,510	3,191 1	15 636	11,020	158 5	193457000
1966	12,080	3,399 1	15 307	11,510	157 1	195499000
1967	12,560	3,484 6	15 056	12,080	155 8	197375000
1968	13,390	3,652 7	14 547	12,560	158 4	199312000
1969	14,140	3,765 4	14 498	13,390	159 7	201298000
1970	14,697	3,771 9	14 113	14,140	162 3	203798722
1971	15,213	3,898 6	14 414	14,697	161 0	206817509
1972	16,367	4,105 0	13 967	15,213	158 4	209274882
1973	17,308	4,341 5	15 085	16,367	155 8	211349205
1974	16,653	4,319 6	23 997	17,308	153 2	213333635
1975	16,322	4,311 2	24 552	16,653	149 4	215456585
1976	17,461	4,540 9	24 783	16,322	149 4	217553859
1977	18,431	4,750 5	24 356	17,461	145 5	219760875
1978	18,847	5,015 0	23 769	18,431	141 6	222098244
1979	18,513	5,173 4	29 982	18,847	137 7	224568579
1980	17,056	5,161 7	45 123	18,513	133 8	227224719
1981	16,058	5,291 7	60 172	17,056	131 2	229465744
1982	15,296	5,189 3	50 88	16,058	129 9	231664432
1983	15,231	5,423 8	45 283	15,296	126 0	233792014
1984	15,726	5,813 6	42 883	15,231	123 4	235824907
1985	15,726	6,053 7	38 544	15,726	119 5	237923734
1986	16,281	6,263 6	19 653	15,726	115 6	240132831
1987	16,665	6,475 1	23 346	16,281	115 6	242288936
1988	17,283	6,742 7	18 316	16,665	114 3	244499004
1989	17,325	6,981 4	22 03	17,283	113 0	246819222
1990	16,988	7,112 5	26 4	17,325	111 7	249622814
1991	16,714	7,100 5	20 907	16,988	113 0	252980941
1992	17,033	7,336 6	19 62	16,714	111 7	256514224

APPENDIX B – RAW DATA

(continued)

annual	U S demand (thousands/b)	real GDP in 2000 dollars(Billions of Dollars)	real price adjusted in 2000 dollars ($/b)	previous demand (thousand/b)	Energy/GDP ratio (base year = 2000)	U S population
	D	Y	P	D_{t-1}	E/G	
1993	17,237	7,532 7	16 986	17,033	110 4	259918588
1994	17,718	7,835 5	15 327	17,237	109 1	263125821
1995	17,725	8,031 7	16 521	17,718	109 1	266278393
1996	18,309	8,328 9	20 269	17,725	107 8	269394284
1997	18,620	8,703 5	18 488	18,309	107 8	272646925
1998	18,917	9,066 9	11 479	18,620	105 2	275854104
1999	19,519	9,470 3	16 089	18,917	102 6	279040168
2000	19,701	9,817 0	26 72	19,519	100 0	282177754
2001	19,649	9,890 7	21 228	19,701	97 4	285093813
2002	19,761	10,074 8	21 542	19,649	94 8	287973924
2003	20,034	10,381 3	25 778	19,761	90 9	290809777
2004		10,841 6	35 262	20,034		

Data source U S demand for crude oil from http //www eia doe gov
Real U S GDP and U S population from Economagic Databases
Domestic crude oil price from http //inflationdata com
Energy/GDP ratio from Federal Reserve Bank of Dallas (working paper 0304)

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