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A Compact Model of Oil Supply Disruptions

David B. Reister

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ABSTRACT

We have developed a model of oil price jumps caused by oil supply disruptions. The core of the model is a compact general equilibrium model of oil demand. Given an exogenous forecast of oil supply and potential GNP for the world, the model can forecast the oil price, real GNP, and Value Added for the world.

The data base for the model consists of historical time series of world oil supply, world oil price, and growth rates for world GNP. The data demonstrate that small changes in oil supply are associated with large changes in oil price.

If a large change in oil price causes a small change in oil consumption, the short-run price elasticity of demand must be small. We have specified a model with a short-run and a long-run price elasticity. The six parameters in the model have been estimated using historical data for three cases.

The initial model had five parameters. For Case 1, we used a search procedure to determine the parameters that minimized the root mean square (RMS) of the differences between the price backcast by the model and the historical data on oil price. We found that the RMS error was 121% and that the price calculated by the model was too low for the period from 1974 to 1980.

After a review of the historical data on oil consumption, oil price, and world GNP, we concluded that the response of the world oil market to the 1974 oil price shock was different than the response to the 1979-80 oil price shock. After the jump in oil price from 1973 to 1974, the consumption of oil decreased in 1975 but quickly recovered and reached a peak in 1979. After the jump in oil price from 1978 to 1980, the consumption of oil declined steadily for four consecutive years.

To improve the model's capacity to simulate the historical data, we introduced a technological change factor that increases the demand for oil in the period from 1971 to 1979. For Case 2, the rate of technological change is 3.8% and the RMS error is 35%. For Case 3, the rate of technological change is 7.0% and the RMS error is 35%. Although Case 3 has the smallest error, we concluded that the Case 2 set of parameters provided the best match for the historical data on world oil price.

For Case 2, we find a small short-run elasticity (-0.09), a substantial long-run elasticity (-0.92), and a lag of 0.08, which corresponds to 12 years. We have invented an oil price scenario that is similar to the historical data and have determined the corresponding oil supply scenario for the Case 2 set of parameters.

1. INTRODUCTION

Since 1970, the world has been buffeted by three oil supply disruptions: 1973, 1979, and 1986. In the first two disruptions, the oil supply was reduced and the oil price increased. In the most recent disruption, the oil supply was increased and the price decreased. In the conventional wisdom of 1978, the world was in a transition from inexpensive oil to expensive oil. Thus, the price increases in 1973 and 1979 were viewed as milestones on the road to expensive oil.

The collapse in oil price in 1986 was unexpected and was probably caused by Saudi Arabia. From a peak of 9.9 million barrels per day (MBD) in 1980, oil production by Saudi Arabia had decreased to 2.3 MBD in August 1985.[1] Beginning in September 1985, production by Saudi Arabia increased and reached 4.7 MBD by December 1985. Starting from $27 per barrel in November 1985, world oil prices began a rapid decline and reached $11 per barrel in July 1986.

World oil production increased from 51.2 MBD in August 1985 to 55.6 MBD in December 1985; an increase of 4.4 MBD. In 1984, the increase in production from August to December was 0.9 MBD for the world and -0.9 MBD for Saudi Arabia. Thus, the oil price collapse appears to have been triggered by an oil surplus of 3.5 MBD and Saudi Arabia was responsible for 3.3 MBD of the surplus.

In this paper, we will develop a compact model of the world oil market and use the model to explore the relationship between supply and price. Clearly, the world oil market is a sensitive system, with small changes in supply causing large changes in price. For the oil price collapse of 1986, a 6% increase in oil supply caused a 59% decrease in oil price and the short-run price elasticity of demand was -0.07.

The oil price increased from $22.50 per barrel in 1978 to $44.09 per barrel in 1980 and consumption fell from 62.4 MBD in 1979 to 52.9 MBD in 1982. From 1979 to 1982, the world GNP increased by 4%. If we assume that oil consumption would have increased with world GNP, the three-year price elasticity of demand was -0.3.

Thus, the oil market appears to have both a small short-run elasticity and a larger long-run elasticity. To simulate historical data, our model will have both a short-run and a long-run price elasticity of demand.

From 1979 to 1985, world consumption of oil decreased by 9.4 MBD, OPEC production decreased by 14.9 MBD, and non-OPEC production increased by 5.5 MBD. In response to the price increase from 1978 to 1980, non-OPEC oil production increased substantially. However, OPEC (led by Saudi Arabia) reduced production and prevented a rapid decrease in price. In 1985, Saudi Arabia decided it could not continue to reduce production and triggered the price collapse.

We will not attempt to simulate the behavior of OPEC and non-OPEC oil producers. We will assume that the oil supply is exogenous. Thus, our model of the world oil market has an oil demand model with both short-run and long-run price response and an exogenous oil supply.

In the next section, we will specify our model. In the third section, we will estimate the parameters in the model. In the fourth section, we will use the model to simulate future oil price shocks. The fifth section presents our conclusions. Our data base will be presented in an appendix.

2. MODEL

Our model has the same accounting structure as the Elephant-Rabbit (ER) model of Hogan and Manne.[2] The ER model uses a CES production function, while we will use a CES cost function. The ER model has a short-run elasticity, while we will have both a short-run and a long-run elasticity. Another closely related model is the Sweeney model.[3,4]

As an introduction to our model, we will consider a conceptual model with more details. For the conceptual model, the world is divided into regions. For each region, an Input-Output (I-O) table is created. The sectors of the I-O table will include energy (crude oil, natural gas, refined petroleum, coal, electricity, and natural gas) and non-energy goods and services (agriculture, mining, construction, manufacturing, transportation, and services). The inputs to the production function for each sector would include the various types of energy and non-energy goods and services and capital and labor. Each region would produce, import, export, and consume goods and services.

For our compact model, all of the details of the conceptual model are compressed into a few aggregate variables. Our compact model has one region - the world. The model has two sectors: crude oil (U) and all other goods and services (X). Capital and labor are combined into a single factor (K). Crude oil is an intermediate good that is used to produce goods and services (X) (crude oil is consumed to produce refined products that are consumed by other sectors and by final demand). The production function for X has inputs of U and K. Following the accounting structure for the ER model, the production function for U has only one input X (we assume that oil wells are drilled and operated by an oil field service industry). The output of X is consumed by final demand (GNP) and by the crude oil sector (XU).

We begin the mathematical description of the model with the production function for X. The total goods and services of the world (X) are produced from inputs of oil (U) and capital and labor (K):

$$X = f(U,K) \ . \tag{1}$$

If we assume that the price of X is equal to the cost of production:

$$PX*X = PU*U + PK*K \ . \tag{2}$$

where PX, PU, and PK are the prices of X, U, and K. The natural units for X and K are constant dollars. We will assume that PX, PU, and PK are price indexes that are equal to 1.0 in the base year (1971). We will measure X, K, and U in 1985 dollars. In 1971 the crude oil supply for the world was 47.84 MBD (or 17.46 billion barrels per year) and the price was $7.97 per barrel. Thus, the magnitude of U in 1971 was $139 billion 1985 dollars.

The total goods and services are consumed to produce oil (XU) and the world total gross national product (GNP):

$$X = XU + GNP \ . \tag{3}$$

We will distinguish between the selling price of oil (PU) and the production cost of oil (PW). When the oil price suddenly doubles, the increase in production cost will be much smaller. The extra revenue flows to the oil producers. We shall call the difference between price and cost a rent or tax (TX) to remind us that governments can set the tax or collect some of the excess profits:

$$TX = PU - PW . \tag{4}$$

We will assume that the production cost depends on an exogenous base price [BW(t)] and the general price level (PX):

$$PW = BW(t)*PX . \tag{5}$$

The value of the goods and services required to produce oil is equal to the value of the oil:

$$PX*XU = PW*U . \tag{6}$$

Using Eqs. (3), (5), and (6), we can eliminate XU and derive the following expression for the world GNP:

$$GNP = X - BW(t)*U . \tag{7}$$

What is the impact of expensive oil on world GNP? When the price of oil increases, the world has an incentive to conserve oil. If capital and labor are substituted for oil, both the oil consumption (U) and the total goods and services (X) will be reduced [see Eq. (1)]. In Eq. (7), the decrease in X decreases the GNP, while the decrease in U increases the GNP. In general, an increase in oil price causes a decrease in GNP, but the impact is small. If no oil conservation occurs, X and U are unchanged and there is no impact on world GNP.

An increase in oil price increases the oil rent (TX) and transfers money from oil consumers to oil producers. The world value added (VA) is the sum of the payments to labor and capital and the oil rent payment:

$$VA = PK*K + TX*U \quad . \tag{8}$$

Using Eqs. (2), (7), and (8), we can show that:

$$PX*GNP = VA \quad . \tag{9}$$

An increase in oil price can have a large impact on value added and the price level (PX), while having a small impact on GNP and oil consumption (U).

Our arguments depend on **ceteris paribus** (other things being equal). We are assuming that there is no change in PK or K, but we know that an increase in the price level (PX) has an impact on payments to labor and capital (PK). An increase in oil price can cause a worldwide recession and cause unemployment (an increase in unemployment reduces K). An increase in oil price can make capital (large cars) obsolete, while a decrease in oil price has reduced the value of the capital stocks in Texas.

The financial system must move money from OECD to OPEC and back again. If OPEC does not spend its extra revenues on goods and services or invest in OECD, the reduction in demand for goods and services could lead to a worldwide recession.

We want the model to have both a short-run and long-run price elasticity of demand. In the model, we will use both a short-run and a long-run cost function:

$$PX = [\alpha\ PU^{\rho} + (1-\alpha)\ PK^{\rho}]^{1/\rho}. \qquad (10)$$

$$PXL = [\beta\ PU^{\gamma} + (1-\beta)\ PK^{\gamma}]^{1/\gamma}. \qquad (11)$$

Both of the cost functions are CES functions. The parameters α and ρ govern the short-run response, while the parameters β and γ govern the long-run response.

Cost functions are a convenient way to specify a model, because Shephard's lemma[5] can be used to derive optimum input-output (I-O) coefficients from a cost function. The I-O coefficient for each factor of production is equal to the partial derivative of the cost function with respect to the price of the factor.

The short-run input-output coefficient for oil (AU) is the amount of oil required to produce a unit of output (U/X). The short-run input-output coefficient for capital and labor (AK) is the amount of capital and labor required to produce a unit of output (K/X). The short-run input-output coefficients for oil and capital-labor are determined by the short-run cost function:

$$AU = \alpha\ (PU/PX)^{\rho-1}. \qquad (12)$$

$$AK = (1-\alpha)*(PK/PX)^{\rho-1}. \tag{13}$$

Similarly, the long-run input-output coefficient for oil (AUL) is determined by the long-run cost function:

$$AUL = \beta\ (PU/PXL)^{\gamma-1}. \tag{14}$$

The parameters ρ and γ control the price response of the model. The short-run price elasticity for oil demand is ρ-1, while the long-run elasticity is γ-1.

We assume that the transition from the short-run to the long-run is controlled by a lag parameter (μ). The short-run input-output coefficient tracks the long-run coefficient; that is,

$$AU_{t+1} = (1-\mu)\ AU_t + \mu\ AUL_t. \tag{15}$$

Using Eqs. (12)-(15), the following expression can be derived for the parameter α:

$$\alpha_{t+1} = \alpha_t\ [1 - \mu + \mu\ (AUL/AU)]\ . \tag{16}$$

In each period, the supply of oil (S) is equal to the demand for oil (U). The supply of oil is exogenous, while the demand for oil is given by:

$$U = g*AU*X\ , \tag{17}$$

where g is an exogenous technological change factor, that we will introduce in the next section. In this section, we will assume that g is equal to 1.0. If X were exogenous, Eq. (17) could be used to determine the price of oil.

However, X is not exogenous, the supply of capital and labor (K) is exogenous. The demand for capital and labor is given by:

$$K = AK*X \quad . \tag{18}$$

To eliminate X, we divide Eq. (17) by Eq. (18) and derive the following market equilibrium equation:

$$U/K = g*AU/AK \quad . \tag{19}$$

The left side of Eq. (19) depends on two exogenous variables (the supply of oil and capital-labor), while the right side depends on the factor g, the parameter α and the prices of oil and capital-labor. If we assume that the price of capital-labor is 1.0, we can solve Eq. (19) for the world oil price;

$$PU = \{[(1-\alpha)/\alpha]\ U/(g*K)\}^{1/(\rho-1)} \quad . \tag{20}$$

Equation 20 is the core of the model. In Eq. (20), the world oil price is determined by the oil supply (U), the factor g, a measure of the level of economic activity in the world (K), and the short-run parameters α and ρ. The dynamics of the parameter α are controlled by Eq. (16).

At the start of each cycle of the model, all of the variables on the right side of Eq. (20) are known and the world oil price can be calculated. Given the world oil price and the price of capital-labor, the short-run input-output coefficients and the long-run input-output coefficients can be calculated [Eqs. (12) and (14)]. Given the input-output coefficients, a new value for the parameter α can be calculated [Eq. (16)] and the model is ready for the next cycle.

Before we estimate the parameters in the model, we will use a few figures to illustrate the features of the model. Equation (20) is a demand curve; a relationship between world oil consumption and world oil price. During an oil supply disruption, the world oil supply is reduced and the world oil price must increase until supply and demand for oil are balanced. Each year α, g, and K are given and the relationship between oil price and oil supply or demand depends on the parameter ρ. In the next section, we will estimate the parameters in the model for three cases. We shall find that the optimum values for the parameter ρ range from 0.83 to 0.93. To generate the demand curve (and the other figures), we will use the parameters for the middle case, for which $\rho = 0.91$. Thus, $1/(\rho - 1) = -11$ and a 1% decrease in oil supply causes a 11% increase in oil price (when PU = 1.0 and PX = 1.0).

Demand curves for 1981 and 1986 are displayed in Fig. 1. In 1981, the world oil consumption was 55.55 million barrels per day and the world oil price backcast by the model was $48.35 per barrel, which was close to the historical price of $43.97 per barrel (historical data are from the appendix). Following the demand curve for 1981, an 8% decrease in supply raises the price to $121, while an 8 % increase in supply lowers the price to \$21 per barrel. In 1986, the world oil consumption was 55.53 million barrels per day and the world oil price backcast by the model was \$16.98 per barrel, which was close to the historical price of \$13.66 per barrel. Following the hypothetical demand curve for 1986, an 8% decrease in supply raises the price to \$42, while an 8 % increase in supply lowers the price to \$7 per barrel.

A useful parameter that can be used to summarize a hypothetical oil demand curve is the demand elasticity (ϵ). The demand elasticity is the percentage change in consumption for a 1% increase in price:

$$\epsilon = \frac{PU}{U} \frac{\partial U}{\partial PU} \quad . \tag{21}$$

The price elasticity for both of the curves in Fig. 1 is $\epsilon = -0.09$. If the magnitude of the price elasticity in 1981 increased to $\epsilon = -0.2$, the price increase for an 8% decrease in oil supply would decrease from \$120 to \$73. Thus, if the demand is more elastic the magnitude of the price changes after an oil supply disruption is smaller.

In Fig. 1, the magnitude of the price change depends on the magnitude of the supply reduction. Stockpiles and surge production capacity mitigate price shocks by reducing the magnitude of the supply reduction. In 1985, the Strategic Petroleum Reserve (SPR) for the United States was about 500 million barrels and the level of oil consumption for the United States was about 15.7 million barrels per day. Thus, the SPR can provide 10% of the oil supply for the United States for about 320 days.

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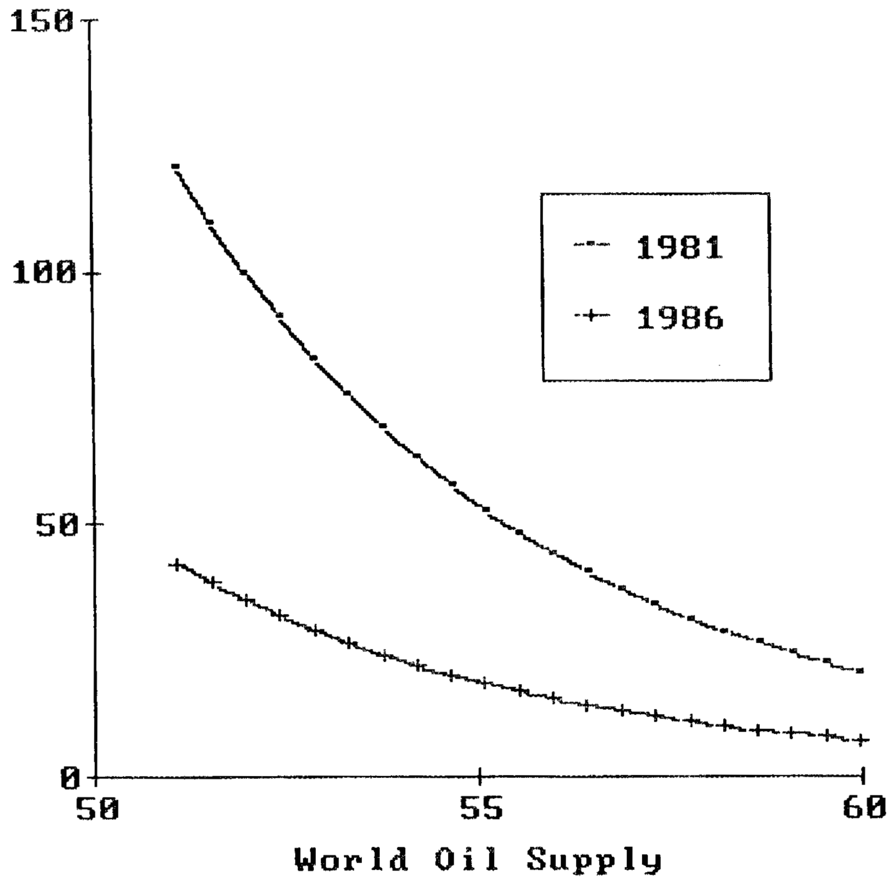

Fig. 1. Hypothetical Oil Demand Curves of 1981 and 1986. Price as a Function of Supply. Units - 1985 Dollars per Barrel and Millions of Barrels per Day.

If an economy has installed furnaces and boilers that can quickly switch from oil consumption to alternative fuels, the magnitude of the price elasticity will be increased and the magnitude of the price shock caused by a supply reduction will be reduced.

For the demand curve for 1981 plotted in Fig. 1, the oil price increases from $21 to $120 per barrel and the total value of the oil increases from 450 billion dollars to 2250 billion dollars; an increase of 1800 billion dollars. Thus, an oil supply disruption can create a large transfer of money from oil consumers to oil producers. In an economy, the sum of all payments to labor, capital, and the government is the value added [see Eq. (8)]. The transfer of money from consumers to producers changes the value added for the world. In Fig. 2, changes in value added for the world are displayed for the two demand curves. Because the price changes for the 1981 demand curve are larger than the price changes for the 1986 curve, the changes in value added are much larger for the 1981 demand curve (1800 billion dollars in 1981 and 650 billion dollars in 1986).

The transfer of money from oil consumers to oil producers creates a potential financial crisis for the world. For the world economy to function smoothly, all of the value added must be spent on goods and services. The oil producers must either buy more goods and services or loan money to oil consumers to buy goods and services.

If all of the value added is spent on goods and services and all of the labor and capital is kept fully employed, the impact of an oil supply disruption on the world GNP is much smaller than the change in value added. Using our model [see Eq. (8)], we can simulate the change in world GNP for the changes in oil supply and price displayed in Fig. 1 (see Fig. 3). With

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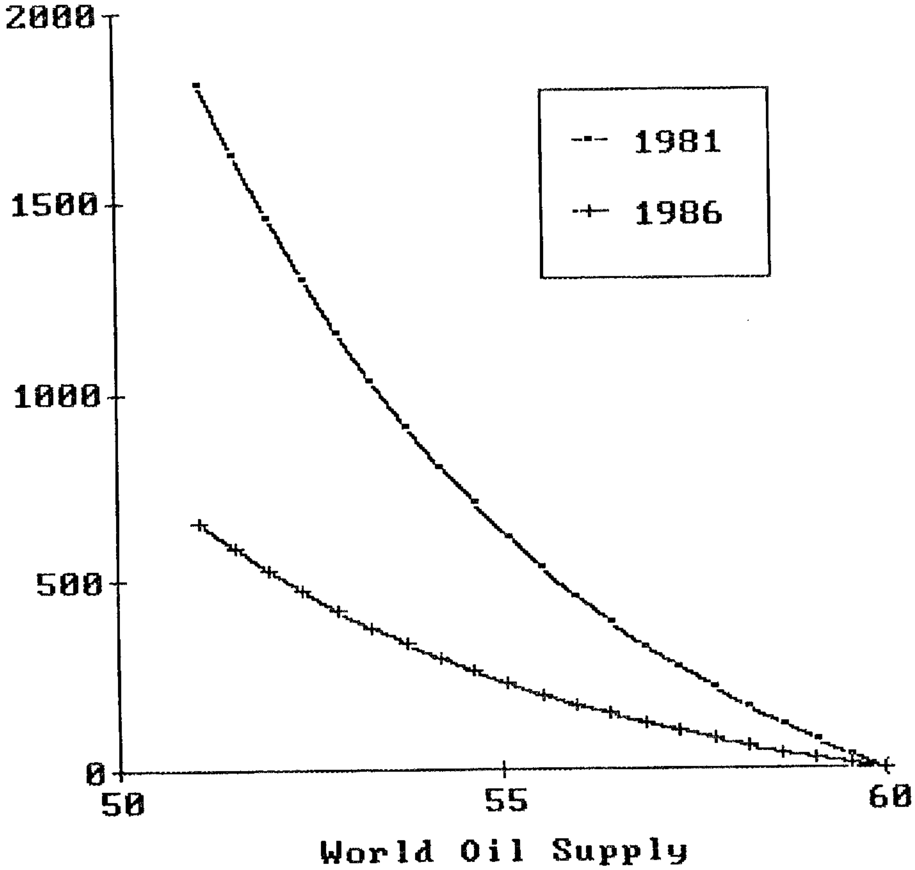

Fig. 2. The Impact of a Reduction in World Oil Supply on World Value Added. Units - Billions of 1985 Dollars and Millions of Barrels per Day.

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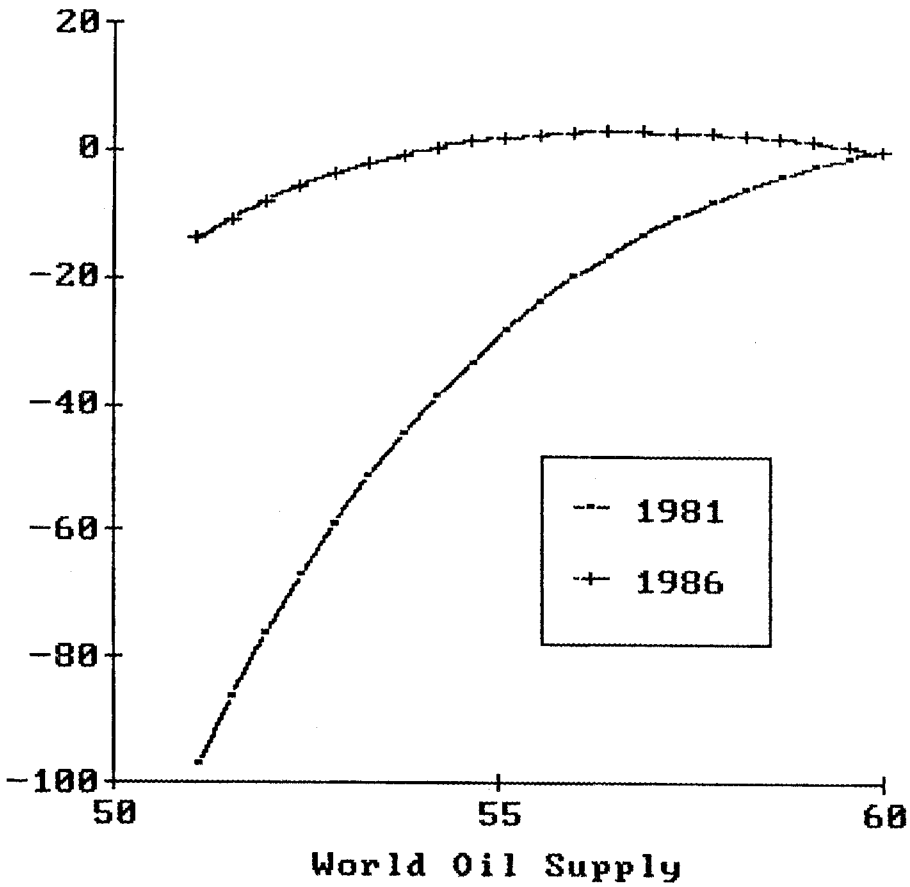

Fig. 3. The Impact of a Reduction in World Oil Supply on the Gross National Product for the World. Units - Billions of 1985 Dollars and Millions of Barrels per Day.

1981 as the base year, an 8% reduction in oil supply reduces the GNP by 73 billion dollars, while an 8% increase in oil supply increases the GNP by 24 billion dollars. With 1986 as the base year, the changes in GNP are much less than when 1981 is the base year.

Since the change in GNP is much less than the change in value added, the oil supply disruption causes a change in the price level. If we assume that the only price change is in the oil price, the change in the price of goods and services (PX) that is forecast by our model is displayed in Fig. 4. With 1981 as the base year, an 8% reduction in oil supply increases the price index by 7%, while an 8% increase in oil supply decreases the price index by 3%.

If wages and interest rates (PK) are increased to compensate for the increase in the cost of goods and services (PX) caused by an oil supply disruption, the change in value added and in the price of goods and services would be higher.

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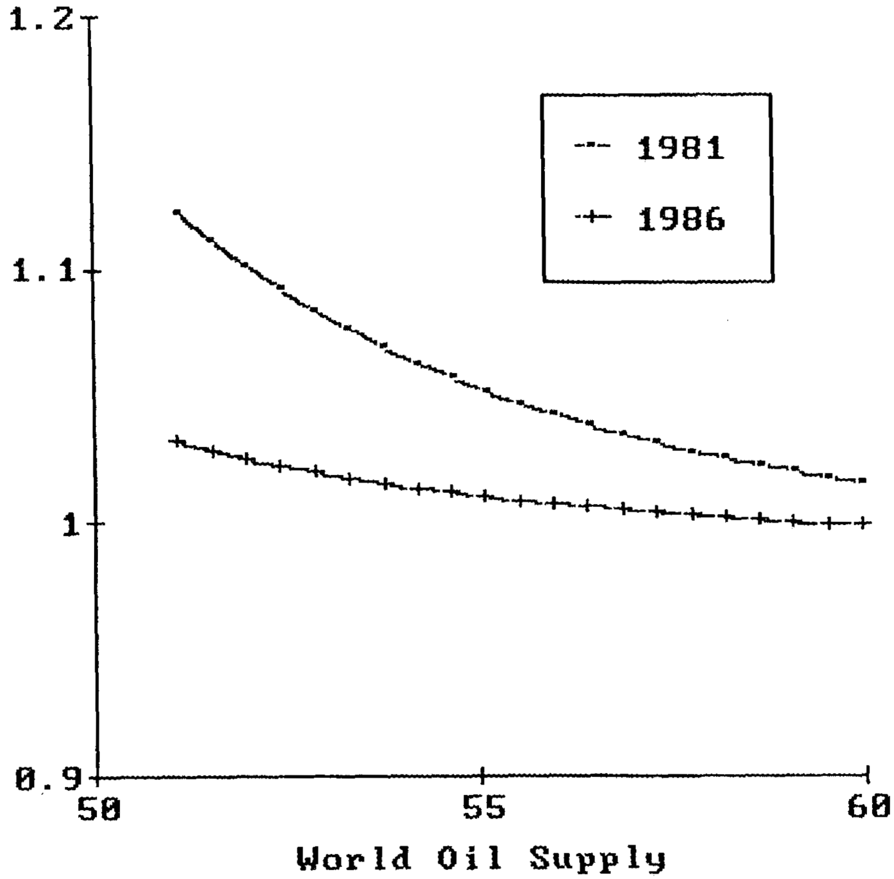

Fig. 4. The Impact of a Reduction in World Oil Supply on the Prices of Goods and Services for the World. Units - Price Index Equals 1.0 in 1971 and Millions of Barrels per Day.

3. ESTIMATION

To estimate the parameters in our model, we need time-series data for world oil consumption, world oil price, and world GNP. For a compact model, a simple data base is appropriate and we have used readily available data. The Annual Energy Review[6] (AER) published by the Energy Information Administration has a time-series on world oil consumption. We will use data for the period from 1971 to 1986.

The proper way to compare prices and output from various countries is to use the purchasing power parity (PPP) method of Kravis and his colleagues.[7,8,9] Using the PPP method, Summers and Heston[10] have estimated time-series of real GNP for selected countries but not for the world. We were unable to find a time-series on real oil price and world GNP constructed using the PPP method.

As an approximation of the real oil price, we will use the average cost of imported crude oil to oil refineries in the United States as reported in the AER. As an approximation of the world GNP, we will use data for the United States to construct a base year (1971) GNP estimate and will use estimates of growth rates in world GNP from a recent International Monetary Fund (IMF) report.[11] Thus, as we move from consumption to price to GNP, the quality of our data base deteriorates. One of the reasons to use compact models is the expense of creating data bases for elaborate models.

The parameters α and β are equal to the ratio of crude oil consumption and total goods and services for the world (X) in the base year. In the base year (1971), we assume that the price indexes, PU and PK, are equal to unity. Consequently, PX and PXL are unity and the base year input-output coefficients are given by: $AU = \alpha$ and $AK = 1 - \alpha$. Thus, $\alpha = U/X$ in the base year.

We will estimate α for the United States and assume that the world has the same value as the United States. If we determine base year values for oil (U) and output (X), we can estimate the parameter α. We assume that the consumption of oil was in equlibrium in 1971 and that $\alpha = \beta$ in the base year.

On page 101 of the 1986 AER, the total consumption of oil in 1971 was 15.21 million barrels per day (MBPD). If we subtract the natural gas plant liquids (1.69 MBPD), the average consumption for crude oil in the United States in 1971 was 13.52 MBPD. On page 135 of the 1985 AER, the average price for imported crude oil in 1971 was $3.17 per barrel. In the September 1986 issue of the Survey of Current Business (SCB),[12] the implicit price deflator for GNP is 44.4 for 1971 and 111.5 for 1985. Thus, using 1985 dollars, the 1971 oil price was $7.96 per barrel and the value of the oil (U) was 39.3 billion dollars.

The most recent estimate of the United States GNP in 1971 is 1102.7 billion dollars.[13] Using 1985 dollars, the GNP in 1971 was 2771.0 billion dollars. Using Equation 7, X is the sum of the GNP and the product of BW and U. We assume that the wellhead price is 75% of the selling price. Thus, BW is 0.75 and X is 2800.5 billion dollars. The parameter α is the ratio of U and X; $\alpha = 0.0140$. Hence, the value of crude oil in 1971 was 1.4% of the total goods and services.

Using Equation 8 for the base year, PK = 1.0 and K is the difference between the value added (VA) and the oil rent (TX*U). For the United States in 1971, the value added was 2771.0 billion dollars and the rent was

25% of 39.3 billion dollars. Thus, K = 2761.1 billion dollars for the United States in 1971. To estimate K for the world, we use the ratio of oil consumption for the world (47.84 MBPD) to oil consumption in the United States (13.52 MBPD) and estimate that K = 9770 billion dollars for the world in 1971. To estimate K for the period 1972 to 1986, we use the IMF growth rates.[11]

The model has five parameters [$\alpha(t)$, β, ρ, γ, and μ]. We have determined the base year values for α and β. We will determine the other three parameters by minimizing an error measure. Given time series data for oil supply (U) and capital-labor (K) and values for the five parameters, we can use Eq. (20) to calculate oil price (PU).

Alternatively, given time series data for PU and K, we could calculate U. If the short-run elasticity is zero ($\rho = 1.0$), we can use Eq.(20) to calculate U but not to calculate PU. As ρ approaches 1.0, small changes in U cause large changes in PU. If we estimate ρ by calculating U, our estimate could approach 1.0. However, if we estimate ρ by calculating PU, our estimate cannot approach 1.0. Thus, calculating PU is the most sensitive way to estimate ρ.

The error measure is the root mean square of the maximum difference percentage for the differences between the calculated oil price and the historical data on oil price. In each year, the maximum difference percentage is the difference between the calculated price and the historical price divided by the smaller of the two prices.

To determine optimum values for the three parameters, we fix ρ and vary γ and μ to minimize the error measure. The parameter γ is related to the long-run elasticity while the lag parameter (μ) controls the speed of the adjustment. We found that the minimum error occurred for very high long-run elasticities and for small values of the lag parameter. A small value for the lag parameter corresponds to a long time for the model to respond to a supply shock. Since we have a small number of data points (16), we placed a lower limit on the lag parameter. We required that μ be greater than or equal to 0.08.

When $\rho = 0.98$, the error is 787%. As ρ decreases, the error decreases to a minimum of 121% when $\rho = 0.93$. As ρ decreases further, the error increases and reaches 147% when $\rho = 0.80$. The set of parameters that minimize the error are $\rho = 0.932$, $\gamma = 0.334$, and $\mu = 0.08$. We shall call this set of parameters, Case 1. The calculated oil price and the historical data on the oil price are displayed in Fig. 5.

In Fig. 5, there is good agreement between the data and the backcast by the model for the preembargo period (1971 to 1973) and after 1981. However, the price calculated by the model is too low for the period from 1974 to 1980. To understand why the calculated price is low, we will review the historical data on oil consumption (see Fig. 6). From 1971 to 1972, world GNP increased by 6% and oil consumption increased by 5.1%. A small increase in calculated oil price was required to reduce the demand for oil. From 1972 to 1973, world GNP increased by 6% and oil consumption increased by 10.6%. A large decrease in calculated oil price was required to increase the demand for oil and the error was 106%. From 1973 to 1974, world GNP increased by 1% and oil consumption increased by 0.4%. A large increase in calculated oil price was required to decrease the demand for oil. But the increase backcast by the model was much less than the historical increase and the error was 224%.

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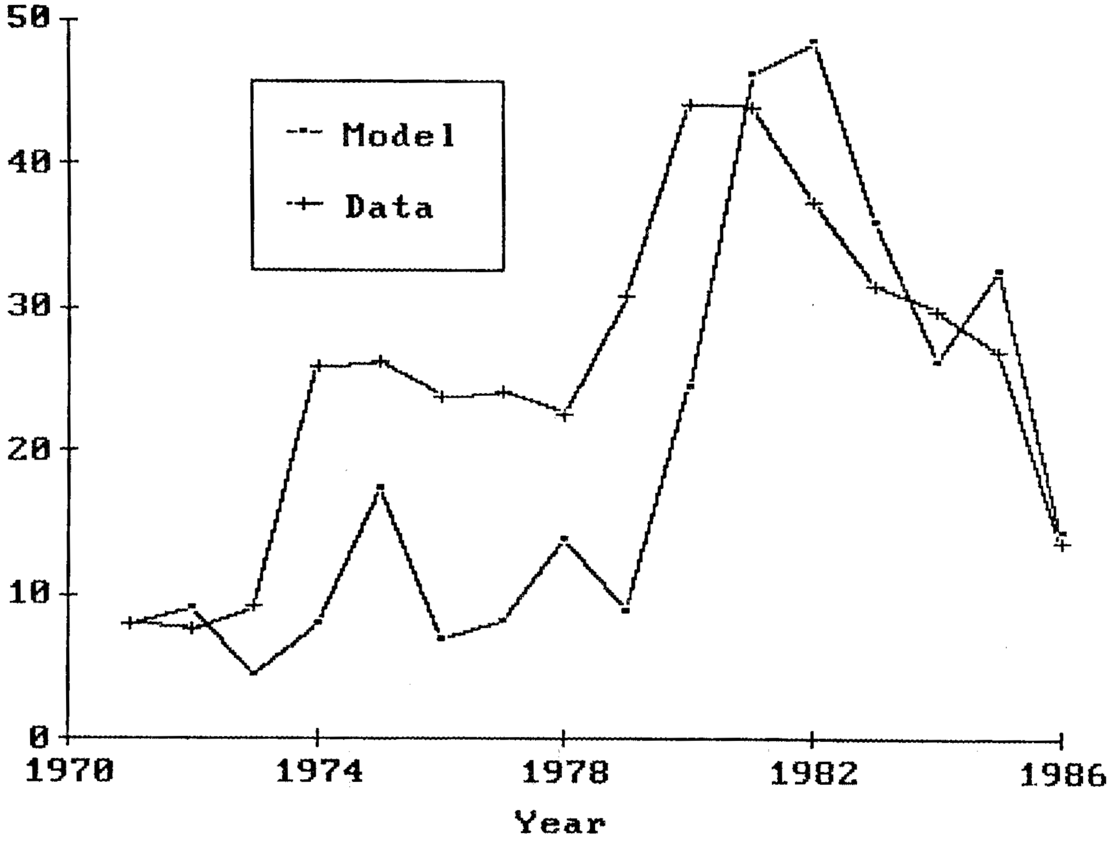

Fig. 5. The Calculated and Historical Oil Prices for Case 1. The Units are 1985 Dollars per Barrel.

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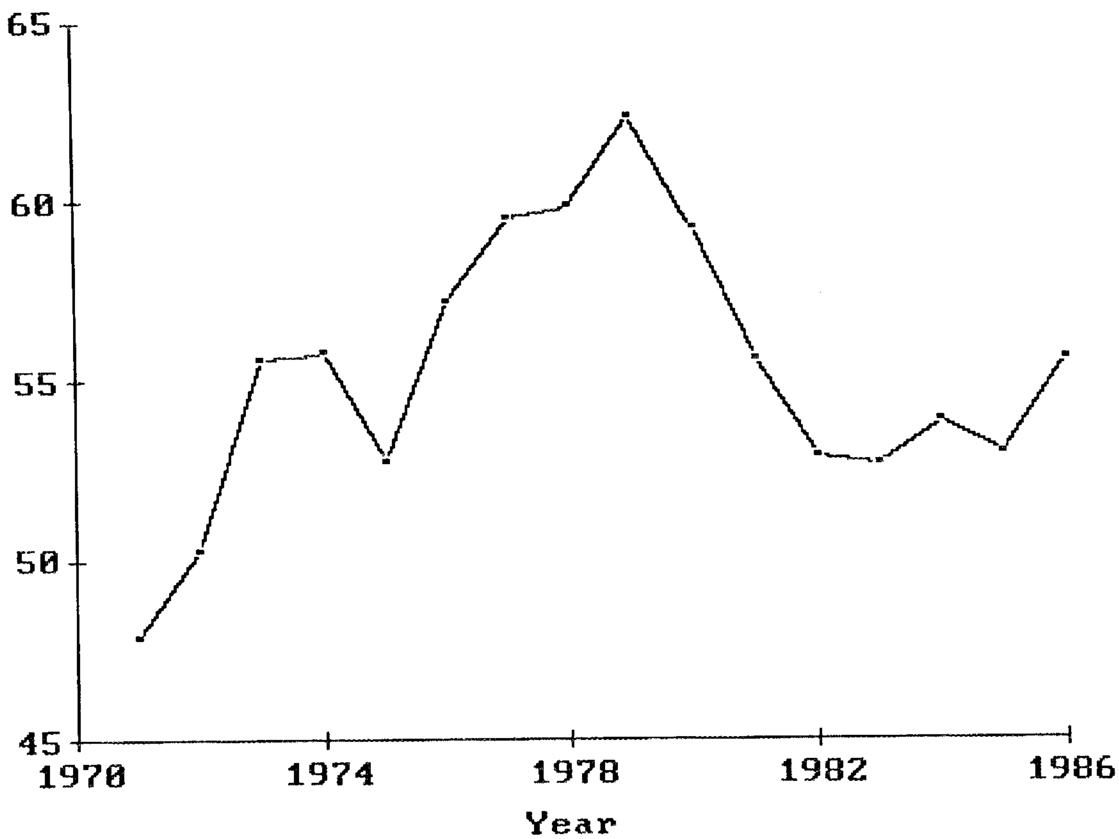

Fig. 6. World Crude Oil Consumption. The Units are Millions of Barrels per Day.

From 1974 to 1975, world GNP was unchanged and oil consumption decreased by 5.4%. A large increase in calculated oil price was required to reduce demand. After the large price jump in 1974, we would expect that the long-run response to the price jump would cause oil consumption to increase less than world GNP. However, from 1975 to 1976, oil consumption increased by 8.4% while world GNP increased by 5%. A large decrease in calculated oil price was required to increase the demand for oil and the error was 247%. From 1978 to 1979, oil consumption increased by 4.1% while world GNP increased by 3.4%. A decrease in calculated oil price was required to increase the demand for oil and the error was 245%.

Our review of the annual growth rates for world GNP and crude oil consumption reveals that oil consumption tended to grow faster than GNP in the period from 1971 to 1979. To stimulate a higher level of demand, the model is forced to underestimate the oil price. Technological change can cause oil consumption to increase at a faster rate than GNP. For example, oil could have been replacing coal in many end-use processes.

To allow oil consumption to grow faster than world GNP, we introduce a technological change factor [g(t)]. In the last section, we introduced the technological change factor [see Eq. (17)] but we did not define it. In this section, our attempt to backcast the historical data has demonstrated the need for a technological change factor. Let g(t) be given by:

$$g(t) = (1 + \delta)^{t - 1971} \tag{22}$$

for t = 1971 to 1979 and g(t) = g(1979) for the period 1980 to 1986.

To estimate the parameter δ, we selected the optimum value for the parameter ρ from Case 1 ($\rho = 0.93$) and varied the other parameters (γ, μ, and δ) to minimize the error. The minimum error occurred for $\delta = 0.038$. Next, we fixed δ, and varied the other parameter to minimize the error measure. The error measure (the root mean square value of the maximum difference percentage) decreased from 121% in Case 1 to 35% in Case 2. The final values for the parameters for Case 2 were: $\rho = 0.909$, $\gamma = 0.084$, $\mu = 0.08$, and $\delta = 0.038$.

The oil price for Case 2 is displayed in Fig. 7. The model results are much closer to the historical data for the period 1974 to 1980 for Case 2 than they were for Case 1. The largest errors are 88% in 1974, 71% in 1972, and 40% in 1976. For both the 1974 price increase and the 1979-1980 price increase, the price backcast by the model lags the historical data by one year. In 1971, the technological change factor causes the model to backcast a price that is too high. Even with the technological change factor, the price for 1976 backcast by the model is too low (the 1976 price backcast by the model increases from $6.86 for Case 1 to $16.98 for Case 2).

The parameters for Case 2 minimize the error measure when $\delta = 0.038$ but they do not minimize the error measure for all values of δ. When we sought a global minimum for the error measure, we found that the technological change factor was becoming too large. For Case 3, we let $\delta = 0.07$ (when $\delta = 0.07$, the technological change factor [g(t)] will double in ten years). The error measure decreased from 121% in Case 1 to 35% in Case 2 and to 29% for Case 3. The final values for the parameters for Case 3 were: $\rho = 0.829$, $\gamma = -0.352$, $\mu = 0.08$, and $\delta = 0.07$.

ORNL-DWG 87-14005

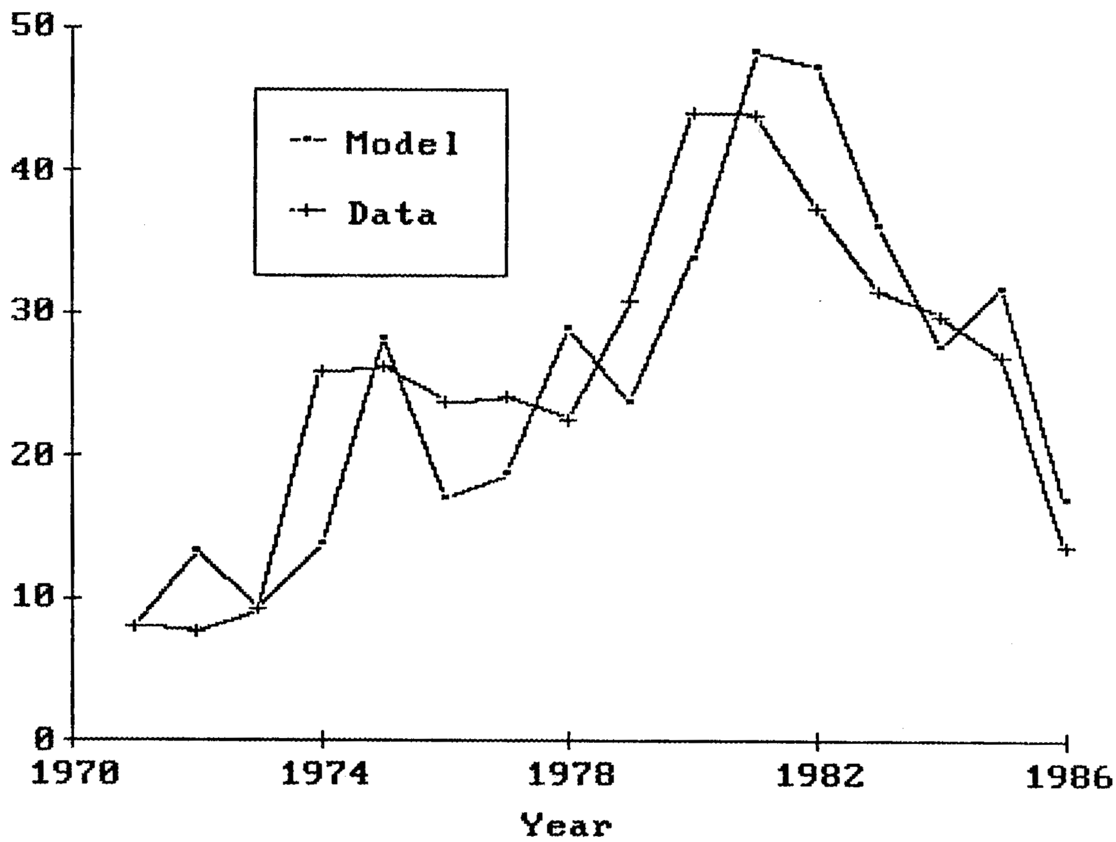

Fig. 7. The Calculated and Historical Oil Prices for Case 2. The Units are 1985 Dollars per Barrel.

The oil price for Case 3 is displayed in Fig. 8. Although the error measure is smaller, the results for Case 3 are not as satisfactory as for Case 2. The model reduces the error in 1974 and 1980 by anticipating the price jumps. Because the oil price backcast by the model was too high before the price jumps, the magnitude of the jumps are too small for Case 3. The magnitude of the price jumps is controlled by the short-run elasticity (the parameter ρ). Thus, the short-run elasticity is in the neighborhood of the value for Case 2 ($\epsilon = -0.09$).

ORNL-DWG 87-14006

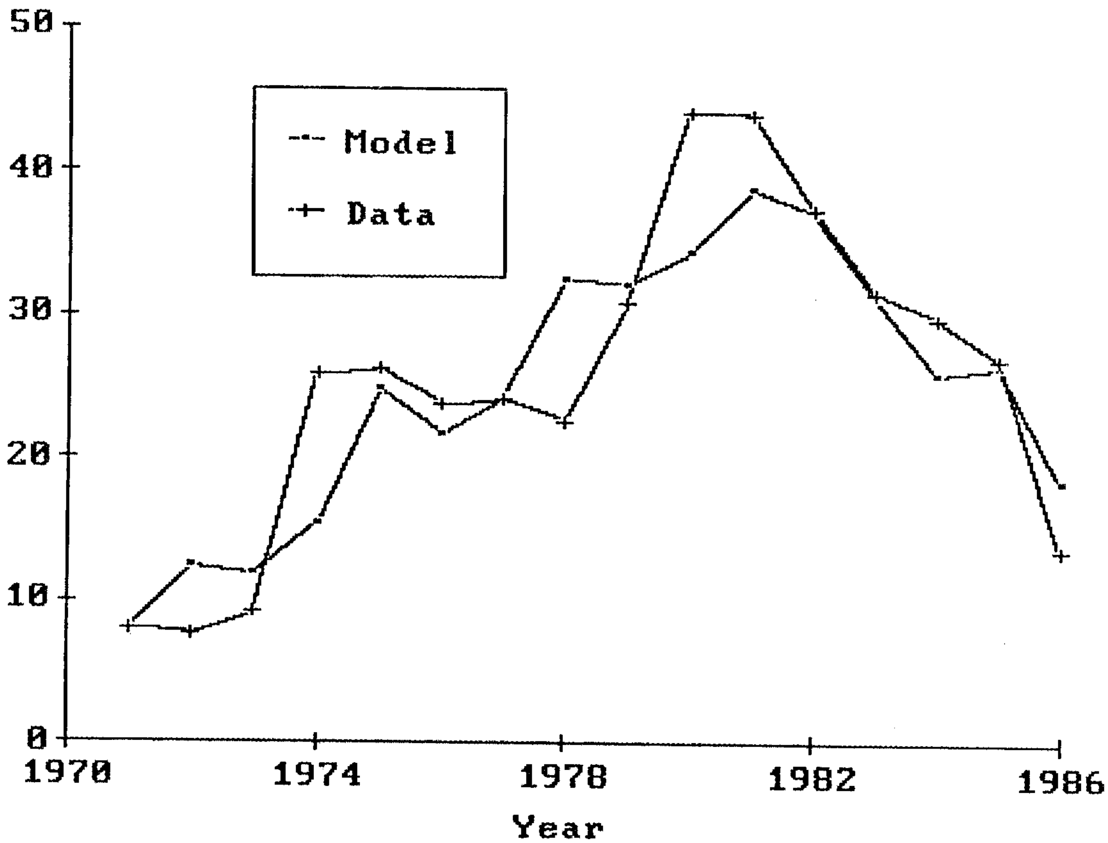

Fig. 8. The Calculated and Historical Oil Prices for Case 3. The Units are 1985 Dollars per Barrel.

4. SIMULATION

We have used the model to create a scenario. The results are displayed in Fig. 9. For the future period (1987-2010), the supply of labor and capital (K) increases linearly. For the scenario, we have adjusted the oil supply (U) to match a price track, that is similar to the historical data on oil price. The parameters for Case 2 were used to create the scenario.

For Case 2, ρ=0.91, the short-run elasticity is -0.09 and a 1% decrease in oil supply causes a 11% increase in oil price. In Fig. 9, small changes in oil supply cause large increases and decreases in oil price. Since γ = 0.08, the long-run elasticity is -0.92 and the oil supply is flat. The historical maximum value for oil consumption was in 1979. For the scenario the future maximum value occurs in 2007. From 1979 to 2007, the world GNP increases by 122% but the oil consumption only increases by 3%.

In Fig. 9, the scenario of future oil supply is not identical to the historical oil supply. However, for the historical period the world did not experience steady economic growth. After the increases in oil price in 1974 and 1979, the world economy had recessions in 1975 and 1981-1983. If we added recessions after oil price jumps, our scenario would be more similar to the historical data. We did not add recessions, because our objective in Fig. 9 is to demonstrate that small changes in oil supply can cause large changes in oil price.

ORNL-DWG 87-14007

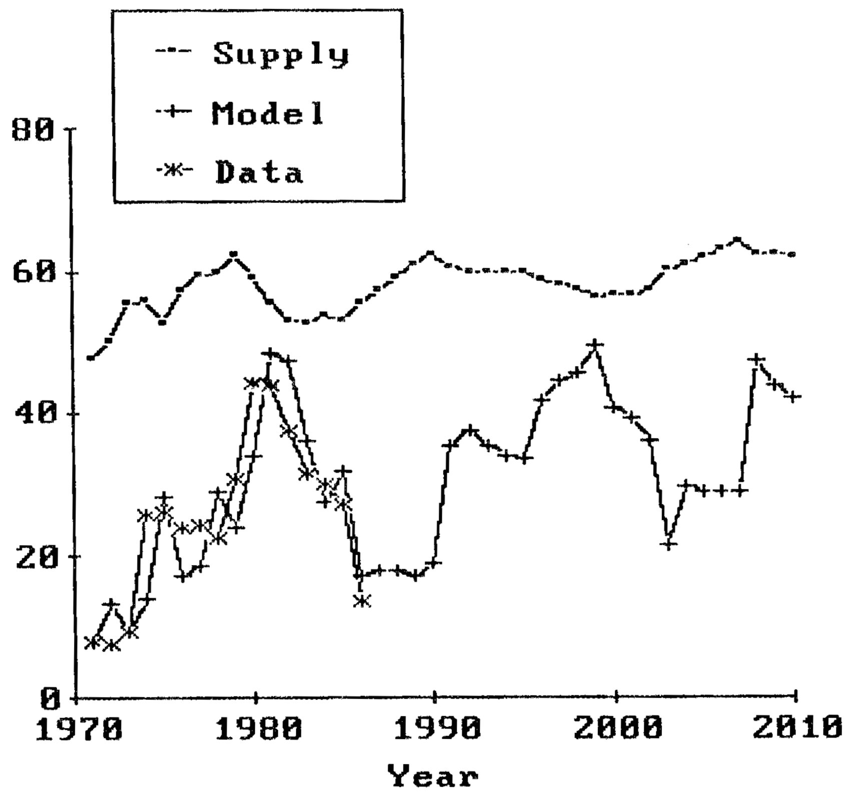

Fig. 9. Small Changes in Oil Supply Cause Large Changes in Oil Price when the Short-Run Price Elasticity is -0.09. Units - Millions of Barrels per Day and 1985 Dollars per Barrel.

5. CONCLUSIONS

We have developed a model of oil price jumps caused by oil supply disruptions. The core of the model is a compact general equilibrium model of oil demand. Given an exogenous forecast of oil supply and potential GNP for the world, the model can forecast the oil price, real GNP, and Value Added for the world.

The data base for the model consists of historical time series of world oil supply, world oil price, and growth rates for world GNP. The data demonstrate that small changes in oil supply are associated with large changes in oil price.

If a large change in oil price causes a small change in oil consumption, the short-run price elasticity of demand must be small. We have specified a model with a short-run and a long-run price elasticity. The six parameters in the model have been estimated using historical data for three cases.

The initial model had five parameters. For Case 1, we used a search procedure to determine the parameters that minimized the root mean square (RMS) of the differences between the price backcast by the model and the historical data on oil price. We found that the RMS error was 121% and that the price calculated by the model was too low for the period from 1974 to 1980.

After a review of the historical data on oil consumption, oil price, and world GNP, we concluded that the response of the world oil market to the 1974 oil price shock was different than the response to the 1979-80 oil price shock. After the jump in oil price from 1973 to 1974, the consumption of oil decreased in 1975 but quickly recovered and reached a peak in 1979. After the jump in oil price from 1978 to 1980, the consumption of oil declined steadily for four consecutive years.

To improve the model's capacity to simulate the historical data, we introduced a technological change factor that increases the demand for oil in the period from 1971 to 1979. For Case 2, the rate of technological change is 3.8% and the RMS error is 35%. For Case 3, the rate of technological change is 7.0% and the RMS error is 35%. Although Case 3 has the smallest error, we concluded that the Case 2 set of parameters provided the best match for the historical data on world oil price.

For Case 2, we find a small short-run elasticity (-0.09), a substantial long-run elasticity (-0.92), and a lag of 0.08, which corresponds to 12 years. We have invented an oil price scenario that is similar to the historical data and have determined the corresponding oil supply scenario for the Case 2 set of parameters.

REFERENCES

1. Monthly Energy Review, Energy Information Administration, Washington, D.C., (January 1987).

2. W. W. Hogan and A. S. Manne (1977). "Energy-Economy Interactions: The Fable of the Elephant and the Rabbit?," in Modeling Energy-Economic Interactions: Five Approaches, edited by C. J. Hitch, Resources for the Future, Washington, D.C.

3. J. L. Sweeney (1978). "Energy and Economic Growth: A Conceptual Framework," Energy Modeling and Net Energy Analysis, Institute of Gas Technology, Chicago, Illinois.

4. J. L. Sweeney (1979). "Energy and Economic Growth: A Conceptual Framework," EMF OP 3.0, Energy Modeling Forum, Stanford University, Stanford, California.

5. R. W. Shephard (1970). Theory of Cost and Production Functions, Princeton University Press, Princeton, New Jersey.

6. Annual Energy Review 1986, DOE/EIA-0384(86), Energy Information Administration, Washington, D.C.

7. I. B. Kravis, Z. Kenessey, A. Heston, and R. Summers (1975). A System of International Comparisons of Gross Product and Purchasing Power, The Johns Hopkins University Press, Baltimore, Maryland.

8. I. B. Kravis, A. Heston, and R. Summers (1978). International Comparisons of Real Product and Purchasing Power, The Johns Hopkins University Press, Baltimore, Maryland.

9. I. B. Kravis, A. Heston, and R. Summers (1982). World Product and Income: International Comparisons of Real Gross Product, The Johns Hopkins University Press, Baltimore, Maryland.

10. R. Summers and A. Heston (1984). "Improved International Comparisons of Real Product and Its Composition: 1950-1980," The Review of Income, **Vol. 30(2)**, pp. 207-262.

11. World Economic Outlook: April 1987, International Monetary Fund, Washington, D.C.

12. Survey of Current Business, United States Department of Commerce, Washington, D.C. (1986).

13. The National Income and Product Accounts of the United States, 1929-82,, United States Department of Commerce, Washington, D.C. (1986).

APPENDIX

This appendix presents the data base for the model (see Table 1). The world oil supply for the period 1971 to 1972 is from page 237 of the AER (Ref. 6). The world oil supply for the period 1973 to 1986 is from page 111 of the MER (Ref. 1). The current dollar oil price is from page 135 of the AER and from page 91 of the MER. The price indexes in Table 1 were used to convert from current dollars to 1985 dollars. The implicit price deflators for GNP are from the September 1986 issue of the SCB (Ref. 12). The growth rate estimates for world GNP are from the IMF report (Ref. 11).

Table 1. Historical Data for World Oil Supply, World Oil Price, and the Growth Rate for World GNP.

The units are millions of barrels per day and dollars per barrel.

Year	Supply[a]	Price[b]		GNP[c]	
		Current $	1985 $	Price	Rate
1971	47.84	3.17	7.97	44.4	4.0
1972	50.26	3.22	7.72	46.5	6.0
1973	55.57	4.08	9.19	49.5	6.0
1974	55.77	12.52	25.87	54.0	1.0
1975	52.76	13.93	26.19	59.3	0.0
1976	57.19	13.48	23.83	63.1	5.0
1977	59.52	14.53	24.08	67.3	4.5
1978	59.87	14.57	22.50	72.2	4.4
1979	62.35	21.67	30.76	78.6	3.4
1980	59.22	33.89	44.09	85.7	2.1
1981	55.55	37.05	43.97	94.0	1.8
1982	52.90	33.55	37.41	100.0	0.6
1983	52.65	29.30	31.46	103.9	2.6
1984	53.83	28.88	29.85	107.9	4.4
1985	52.95	26.99	26.99	111.5	3.1
1986	55.53	13.98	13.66	114.1	2.9

a. The world oil supply for the period 1971 to 1972 is from page 237 of the AER (Ref. 6). The world oil supply for the period 1973 to 1986 is from page 111 of the January 1987 issue of the MER (Ref. 1).

b. The current dollar oil price is from page 135 of the AER and from page 91 of the MER. The price indexes in the next column of this table were used to convert from current dollars to 1985 dollars.

c. The implicit price deflators for GNP are from the September 1986 issue of the SCB (Ref. 12). The growth rate estimates for world GNP are from the IMF report (Ref. 11).

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