ORNL/TM-2005/45

Costs of U.S. Oil Dependence: 2005 Update

January 2005

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February 2005

Prepared by
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managed by
UT-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and especially the guidance and encouragement of Dr. Philip Patterson. We thank our colleagues at Oak Ridge National Laboratory for their insights and critical review of an earlier version of this report especially Paul Leiby and Randy Curlee. We thank Debbie Bain for painstakingly preparing this manuscript. Any errors herein are solely our responsibility. This report is dedicated to Michael D. Greene and Barry D. McNutt.

ABSTRACT

For thirty years, dependence on oil has been a significant problem for the United States. Oil dependence is not simply a matter of how much oil we import. It is a syndrome, a combination of the vulnerability of the U.S. economy to higher oil prices and oil price shocks and a concentration of world oil supplies in a small group of oil producing states that are willing and able to use their market power to influence world oil prices. Although there are vitally important political and military dimensions to the oil dependence problem, this report focuses on its direct economic costs. These costs are the transfer of wealth from the United States to oil producing countries, the loss of economic potential due to oil prices elevated above competitive market levels, and disruption costs caused by sudden and large oil price movements. Several enhancements have been made to methods used in past studies to estimate these costs, and estimates of key parameters have been updated based on the most recent literature. It is estimated that oil dependence has cost the U.S. economy $3.6 trillion (constant 2000 dollars) since 1970, with the bulk of the losses occurring between 1979 and 1986. However, if oil prices in 2005 average $35-$45/bbl, as recently predicted by the U.S. Energy Information Administration, oil dependence costs in 2005 will be in the range of $150-$250 billion. Costs are relatively evenly divided between the three components. A sensitivity analysis reflecting uncertainty about all the key parameters required to estimate oil dependence costs suggests that a reasonable range of uncertainty for the total costs of U.S. oil dependence over the past 30 years is $2-$6 trillion (constant 2000 dollars). Reckoned in terms of present value using a discount rate of 4.5%, the costs of U.S. oil dependence since 1970 are $8 trillion, with a reasonable range of uncertainty of $5 to $13 trillion.

1. INTRODUCTION

This is the fourth in a series of reports on the economic costs to the United States of its dependence on petroleum.[1] Although there are very important military, strategic and political costs of oil dependence (e.g., see Leiby et al., 1995) this series has dealt only with direct economic costs because they are relatively well defined, measurable, significant and too frequently overlooked. Through the year 2000, the cumulative costs of oil dependence were estimated to be $4 trillion in constant $2000 dollars or $7 trillion if the dollars are converted to present value (Greene and Tishchishyna, 2001). This study updates those cost estimates to 2004, introduces some improvements to the estimation methodology, and includes projections for 2005.

Oil dependence is not simply a matter of how much oil we import. It is a syndrome, a combination of factors that together create economic, political and military problems. It is comprised of the concentration of the world's oil supply in a small group of oil producing states that wield monopoly power, together with the demand-side vulnerability of the U.S. economy to higher oil prices and price shocks. Our vulnerability depends on how much oil we consume, the lack of ready substitutes for oil, and also how much we import. Political, social and religious conflicts between the oil producing and consuming nations complicate the economic, strategic and military dimensions.

This report updates estimates of historical costs through 2004 and projects costs in 2005 based on current oil price projections of the U.S. Energy Information Administration. Several improvements have been made to the cost estimation methods, key parameters have been revised based on the recent literature, and risk analysis methods have been used to better reflect the inherent uncertainty about critical assumptions. We find that the costs of oil dependence through 2004 have been approximately $3.6 trillion in constant year 2000 dollars. If past costs are converted to present value, the costs amount to approximately $8 trillion. *Throughout this report, costs will be reported in constant 2000 dollars*. The risk analysis gives a 90% sensitivity interval of $2.1 trillion to $6.2 trillion for the reference case assumptions. The econometric literature suggests that the economy's vulnerability to oil price shocks has not decreased over time, an assumption not fully accepted in the reference case. Assuming a constant oil price elasticity of GDP results in higher cost estimates of $3.9 trillion ($8.4 present value). Sensitivity analysis demonstrates that the cost estimates produced by the method used in this study are robust to even large changes in key assumptions.

In estimating the economic costs of oil dependence we have not included the real and substantial costs to society of policies implemented to deal with the problem. Chief among such costs are military expenditures related to protecting oil supplies from the Persian Gulf and the creation and maintenance of the Strategic Petroleum Reserve (e.g., see Delucchi, 1996; Leiby et al., 1995; and Parry and Darmstadter, 2003 for reviews and discussion of these issues). Such costs are not considered here, not because they are unimportant, but because they are so different by nature and with respect to the methodological issues they raise.

[1] The three previous reports are: Greene and Leiby, 1993; Greene, Jones and Leiby, 1995; 1998; Greene and Tishchishyna, 2001.

2. THE NATURE OF THE OIL DEPENDENCE PROBLEM

The United States' dependence on oil has been a serious national concern since the first oil price shock in 1973. However, even today there is not a consensus on the definition of oil dependence and how to measure its economic costs. The principal reason for this is that the problem of oil dependence is not one dimensional. It is not merely a matter of how much oil is imported, although the volume of imports matters. It is not entirely a matter of how much oil is consumed, although that too is important. The lack of economical substitutes for oil, especially in the transportation sector, is also a key element. The concentration of oil resources in a relatively few countries that have demonstrated the desire and capability to influence world oil prices is an essential ingredient (Kaufmann et al., 2004). Oil dependence should be seen as a syndrome, a combination of the importance of oil to the economy, reliance on imports, lack of economical substitutes, and the use of market power by oil producing states. These factors have combined to cost the U.S. economy trillions of dollars over the past 30 years (Greene and Tishchishyna, 2001).

Oil is a critical resource for which there are still inadequate substitutes in the economically vital transportation sector. Thirty years after the Arab-OPEC oil embargo of 1973-74 the U.S. transportation system remains dependent on petroleum for 97% of its energy needs (US DOE/EIA, 2004b, table 2.1e). The U.S. economy is increasingly relying on imported petroleum to satisfy its growing demand. In 1973 net imports of petroleum supplied 35% of total U.S. oil consumption. This grew to 47% in 1977, but increased domestic supply from Alaska and reduced domestic demand as a result of higher oil prices and energy efficiency regulations drove imports down to 27% of total consumption in 1985. Since the oil price collapse of 1986, U.S. net oil import dependence has gradually risen to 58% (through October 2004). Net oil imports are at their highest levels ever, 11.8 million barrels per day (mmbd). Record import levels and oil spot market prices peaking at $55/bbl (nominal $) will likely lead to near-record expenditures on oil imports in 2004 and 2005 (Figure 1).

Importing so much of a critical energy resource would be much less of a problem were it not for the fact that so much of the world's oil supply and oil resources are concentrated in a relatively few countries, countries that have demonstrated a willingness to use monopoly power to manipulate price (Kaufmann et al., 2004). According to the economic theory of partial monopolies, the market power of the OPEC cartel depends on three key factors (Greene, 1991): (1) the cartel's share of the world oil market, (2) the price elasticity of world oil demand, and (3) the price elasticity of non-OPEC oil supply.[2] In a dynamic market, market power also depends on the rate of growth of oil demand and the rate of change, if any, of non-OPEC supply (Greene, Jones and Leiby, 1998).

[2] These three factors together determine the net price elasticity of demand for OPEC oil. For purposes of understanding the nature of the oil dependence problem and what may be done about it, it is useful to list them separately.

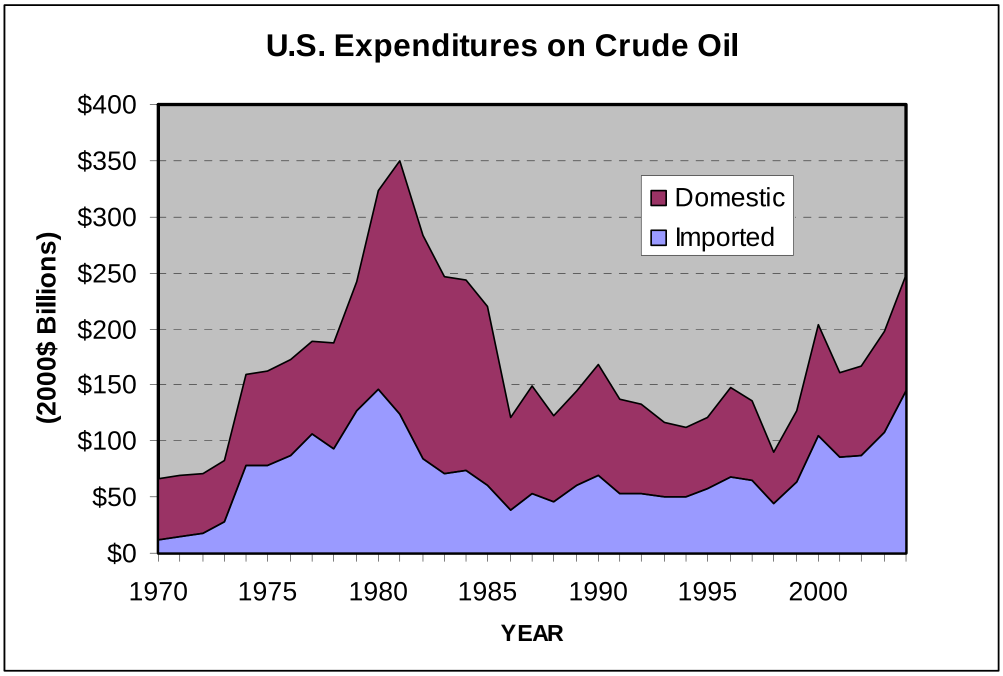

Figure 1. U.S. Expenditures on Crude Oil, 1970-2004 (est.)

Comprehensive studies of the economic costs of oil dependence tend to fall into two categories: (1) those that treat the economic costs as arising from the use of monopoly power in the world oil market (Greene and Leiby, 1993; Greene, Jones and Leiby, 1998; Greene and Tishchishyna, 2001), and (2) those that treat the costs of oil dependence as external costs, arising from a variety of phenomena (Leiby et al., 1995; Delucchi, 1997; Moore, Behrens and Blodgett, 1998; Parry and Darmstadter, 2003). The chief differences between the two approaches are in their diagnosis of the nature of the problem and the choice of what to compare the actual situation to. Studies that take the first approach assume that monopoly power is the key market failure and compare the actual situation to a hypothetical competitive world oil market or to a market in which OPEC's market power is significantly reduced (e.g., Greene, Jones and Leiby, 1998). Studies that take the second approach assume that failure to internalize external costs in oil prices is the key market failure and compare the actual situation to one in which external costs are internalized. Studies of the external costs type generally include a wider array of external costs, from greenhouse gas emissions to military costs of securing oil supplies.

Some analysts have confused the two perspectives, arguing that since externalities are market failures, and oil dependence reflects a market failure, then oil dependence should be treated as if it were an externality. Not recognizing this as a logical fallacy, the analysts cast oil dependence in terms of external costs, estimate the external costs, and then conclude that a tax reflecting those external costs represents all that is economically justifiable to deal with oil dependence. Referring to the Pigouvian externality tax as a premium, Parry and Darmstadter (2003, p. 2) make precisely such a fallacious assertion.

> "The premium reflects the extent to which the costs to the United States from an extra barrel of petroleum consumption exceeds (sic) the private costs paid by oil users; it tells us how much policy intervention to reduce oil dependency is warranted on economic grounds through, for example, energy conservation measures."

The first part of the assertion is accurate; the authors have attempted to estimate marginal social costs of petroleum consumption due to two phenomena: (1) the monopsony power of the United States which accounts for 25% of world oil consumption, and (2) the disruption costs of possible future oil price shocks. The second part of the assertion is incorrect, because the market failure at the heart of the oil dependence problem is monopoly power on the part of the OPEC cartel not the external costs that are byproducts of the competitive market failure. An oil premium is not a solution for the market failure of monopoly power and therefore is not a solution for the syndrome of oil dependence, nor does an oil premium fully reflect the economic benefits of reducing oil dependence. Misdiagnosing the problem of oil dependence as an externality leads to severely underestimating the importance of oil dependence to our economy and to inadequate policy prescriptions.

Others (e.g., Leiby et al., 1995) recognize the importance of the market failure of monopoly power in world oil markets but still consider it useful to develop estimates of the marginal social cost of oil use due to monopsony power and oil price shocks. They point out that such estimates could be very useful in formulating pricing policies as one component of a comprehensive strategy to address the problem of oil dependence.

It should be no surprise that the two different diagnoses lead to different estimation methodologies and to very different cost estimates. For example, OPEC successfully raising prices above competitive market levels would be viewed as an economic cost in the first approach, but might be considered a successful internalization of external costs and therefore a reduction in social costs by the second. Acknowledging the importance of externalities associated with oil use, such as greenhouse gas emissions, the objective of this study is to estimate the direct economic costs to the U.S. of the market failure of monopoly power in the world oil market.

The two different diagnoses (externality vs. monopoly power) also lead to very different conclusions about how to solve the problem of oil dependence. If oil dependence is an externality, the most appropriate policy intervention is to internalize that externality in oil prices, e.g., via a tax on petroleum. But if market power is the problem and breaking up the cartel is not an option, the most effective solutions may be largely technological: (1) increasing the range of resources that can be economically converted to petroleum fuels, (2) increasing the efficiency of petroleum use, and (3) developing economically viable substitutes for petroleum. Some measures, such as strategic reserves to mitigate oil supply disruptions, are appropriate under either diagnosis. Failure to recognize that monopoly power is at the core of the oil dependence problem could lead to underinvestment in research and development to produce technological solutions.

It is reasonable to ask whether the competitive market comparison is meaningful since it may not be possible to achieve a fully competitive world oil market. Even if a fully competitive market cannot be achieved, the hypothetical competitive world oil market remains a useful reference point. It is not necessary to achieve a fully competitive market in order to meaningfully reduce the costs of oil dependence. Economic benefits can be achieved by weakening the market power of the OPEC cartel without eliminating it. In a simulation of the possible future costs of oil dependence from 1993-2010, Greene, Jones and Leiby (1998) showed how savings of $0.5 trillion would accrue to the U.S. economy if the price elasticities of oil supply and demand could be doubled by means of advanced technology, despite the continued existence of OPEC.

Recent history contains a clear instance of market forces and energy policies undermining OPEC's market power. The period of high oil prices from 1973-1985 stimulated additional supply from non-OPEC countries and encouraged energy efficiency improvements and fuel switching. Policies such as fuel economy standards further reduced the demand for petroleum.[3] Prior to the first oil price shock in 1973-74, world oil consumption had been growing steadily at an average annual rate in excess of 7% from 1960 to 1973 (US DOE/EIA, 2004b, table 11.10). From 1973 to 1985, world oil consumption fluctuated, ending the 12-year period only 5% higher than the 1973 level (an average annual rate of only 0.4% per year). As a result of the market's response to higher prices and policies requiring energy efficiency improvements, OPEC's share of world crude oil production fell from 55% in 1973 to 30% in 1985 (US DOE/EIA, 2004b, table 11.5). The combination of drastically reduced market share and stagnant growth in oil demand was sufficient to cause the collapse of OPEC's market power and the collapse of monopolistic oil prices in 1986. Although OPEC still possessed some market power at a 30% market share, steadily shrinking revenues undermined the discipline of OPEC member states causing the collapse of the cartel as an effective, partial monopolist. It took almost 15 years for the OPEC cartel to regain a dominant position in the world oil market.

Both the monopoly power and externality methods of analysis can be useful for revealing different aspects of the problem. The externality studies are useful if one is considering how to devise fiscal measures to ameliorate the problem of oil dependence. The monopoly power approach to oil dependence is useful for analyzing the benefits of changing the technological basis of oil consumption, the benefits of additional oil supplies (such as the disputed resources in the Arctic National Wildlife Refuge), or the benefits of regulatory policies, such as energy efficiency standards, that reduce petroleum consumption by non-price mechanisms. It is critically important, however, not to confuse externality cost estimates with the full economic costs of oil dependence. Since the oil dependence syndrome depends strongly on the use of market power, it is in essence an entirely different kind of market failure from an externality and one that cannot be solved, even in theory, solely by adjusting the price of oil. Likewise, it is not possible to estimate the full costs of oil dependence to the U.S. economy by calculating the external costs of oil use.

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[3] Not only did the United States implement mandatory fuel economy standards, but many other developed economies implemented voluntary fuel economy standards which were adhered to (Plotkin, Greene and Duleep, 2002).

3. DEFINITION OF THE ECONOMIC COSTS OF OIL DEPENDENCE

3.1 DEFINITION OF OIL DEPENDENCE

Measuring the economic costs of oil dependence requires a rigorous definition of oil dependence. Much of the confusion about the costs of oil dependence arises from the fact that it has more than one dimension. Oil dependence is a product of the importance of oil to the U.S. economy, the quantity of U.S. oil imports, the inelasticity of world oil demand (particularly in the short run), the ability of the OPEC cartel to manipulate oil prices, and the inelasticity of non-OPEC supply. In this study, oil dependence is defined as the vulnerability to economic costs caused by the use of market power by oil producing countries. This definition includes more than the costs of disruptions caused by oil price shocks. It includes the loss of output due to higher than competitive market prices, and the transfer of wealth from oil consumers to oil producers as a result of monopolistic pricing.

3.2 TYPES AND MEASUREMENT OF OIL COSTS

When monopoly power is used to raise the price of oil above competitive market levels, oil consuming economies incur three types of economic costs: (1) transfer of wealth, (2) reduction of the maximum output the economy is capable of producing due to the increased economic scarcity of oil (loss of potential GDP), and (3) costs of adjusting to sudden, large price changes (macroeconomic adjustment costs). In the absence of sudden price changes, the first and second types of costs still apply as long as monopoly power is used to hold prices above competitive market levels.

3.2.1 Transfer of Wealth

When oil suppliers use market power to raise prices above competitive market levels, wealth is transferred from oil consumers to oil producers. The transfer of wealth is not a loss to the global economy. The wealth still exists, only its ownership has changed.[4] However, from the perspective of the political economy of a state, the loss is real. Oil consuming states become poorer, oil producing states become richer. Since this study is concerned with impacts on the U.S. economy, the transfer of wealth is a real economic loss.

If the hypothetical competitive market price for oil were known, the transfer of wealth could be easily computed. It would equal the quantity of net imports times the difference between the actual market price and the hypothetical price that would prevail in a competitive market. Because the United States now imports 58% of its 20 million barrels per day of oil consumption, the transfer of wealth can be very large. Suppose that the competitive price of oil would have been $15/bbl, but that the actual price was $45/bbl. The transfer of wealth from the U.S.

[4] More precisely, there is no economic loss provided that the cost of producing imported oil is less than the competitive market price. In the case of the OPEC cartel, the higher monopoly price will encourage competitive fringe producers to equate the marginal cost of supplying oil to the monopoly price. In the process, real resources will be expended leading to a deadweight loss. Such losses are counted as transfer of wealth here to simplify the analysis. Thus, some fraction of what is counted here as transfer of wealth is in fact a deadweight economic loss to the world economy.

economy would be (\$45-\$15)×20×0.58 = \$348 million per day or \$127 billion per year. In reality, the hypothetical competitive market price cannot be observed but must be estimated. The path it would have taken over a period as long as 30 years must be considered highly uncertain. This topic is discussed at greater length in the following section.

Wealth transfer losses are illustrated in Figure 2. At the competitive market price, P_C, domestic oil supply is only S_C but domestic demand is D_C. The difference, $D_C - S_C$, is imported. When the price of oil is raised by the use of market power to P_M, demand for oil contracts to D_M, but domestic supply increases to S_M, so that only $D_M - S_M$, is imported. Consumer expenditures on oil were $P_C D_C$ in the competitive market but consumers were receiving in benefits the entire integral under the demand curve from 0 to D_C. Under monopoly pricing, consumers are paying $P_M D_M$ for oil, but receiving in benefits only the integral under the demand curve out to D_M. The triangular area under the demand curve labeled "Consumers' Surplus Loss" is a deadweight economic loss, a potential benefit to consumers that now no one receives. The rectangular area labeled "Wealth Transfer" was consumers' surplus in the competitive market, but is a cash payment to suppliers of imported oil in the non-competitive market. The consumers' loss is the oil exporters' gain. The size of the wealth transfer is $(P_M - P_C) \times (D_M - S_M)$. The triangular area under the supply curve labeled "Producers' Surplus Loss" represents real economic resources spent by domestic oil suppliers to increase production that would not have been spent in the competitive market. This area was formerly consumers' surplus in the competitive market but is now wasted resources that must be paid for by consumers. In the competitive market, these resources would have been put to use producing other goods, thus leading to a higher level of domestic product.

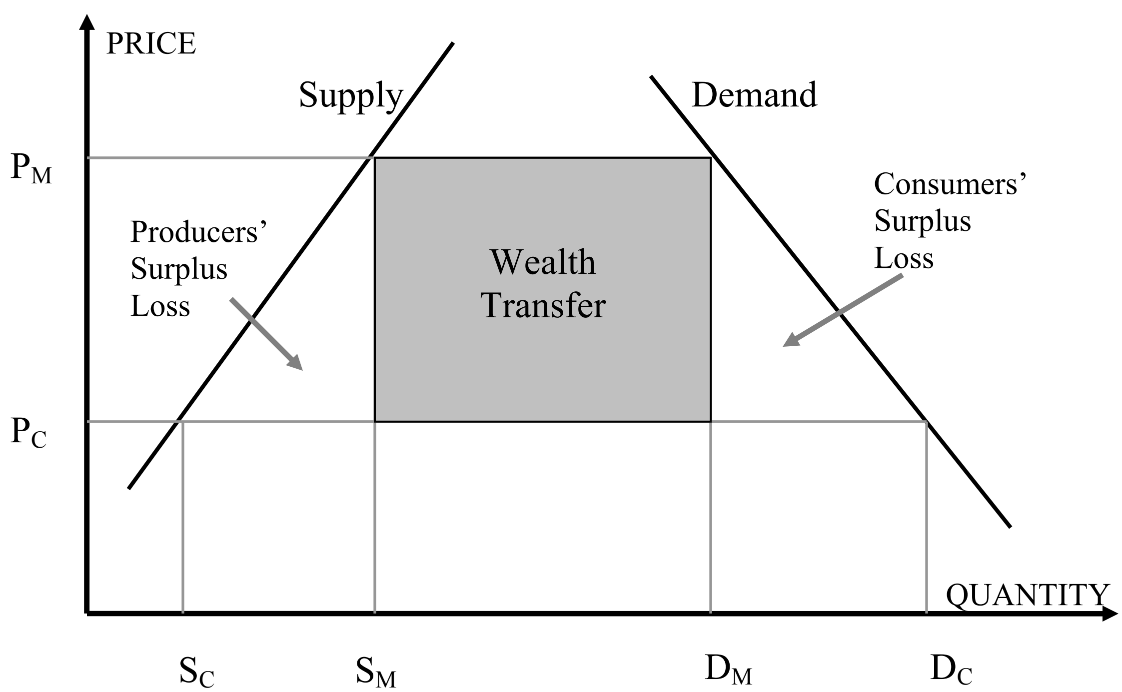

Figure 2. Diagrammatic Representation of Wealth Transfer and Potential GDP Losses

The critical assumption for estimating the transfer of wealth is clearly the hypothetical competitive market price of oil. Fortunately, several researchers have estimated at different points in time what the price of oil would have been had world oil markets been competitive.

Griffin and Vielhaber (1994) put the competitive market price at $8.20/bbl (in 2000 dollars). Other estimates include Adelman's (1989) $7.10 (all prices in 2000 dollars), Morison's (1987) range of $7.10 to $8.70, and Brown's (1987) range of $9.60 to $12.60/bbl. A simulation of competitive oil market conditions by Berg, Kverndokk and Rosendahl (1997) concluded that had OPEC acted as a competitive producer the price of oil in 2000 would have been $12.10. Historically, the price of imported oil to U.S. refiners was $10.67/bbl in 1972, the year before Arab members of OPEC first used their market power to cause the oil price shock of 1973. It had been relatively stable though declining slightly in the previous years. The lowest annual oil price on record since 1973 is $12.48/bbl, in 1998. Modelers' estimates and the historical evidence point to a competitive oil price below $13.00/bbl, even today.

The chief argument in favor of a stable or falling competitive oil price over the 1970-2004 period is the progress of technology. The International Energy Agency has pointed out that "Oil supply costs have fallen considerably in the last 20 years." (IEA, 2001, p. 52) Technological progress has outpaced depletion thanks to advances such as 4D seismic imaging, increased application of computing power to data acquisition and analysis, technological advances in offshore (especially deepwater) drilling, and application of intelligent, multi-directional drilling technology. In the same report, the IEA presented estimates of current total oil supply costs that ranged from $4/bbl for major Middle East producers to $6-$11/bbl for the major international oil companies (IEA, 2001, figure 2.5). Total oil supply costs include direct lifting costs, production costs and finding and development costs. Other factors enter into the determination of competitive market prices, including transportation and the different qualities crude oils from different sources. Still, it would be hard to imagine how the marginal cost of oil in a competitive market today could exceed $15/bbl, if the IEA cost estimates are accurate. In the estimations below, $13/bbl is used as a reference competitive market price of oil.

3.2.2 Potential GDP Losses

When the price of oil is raised above the competitive market level, the higher price signals the economies of the world that oil is scarcer. Economic scarcity, as opposed to physical scarcity, is communicated to economies by higher prices. From an economic perspective, it is unimportant whether the scarcity is due to the exercise of market power or the lack of physical resources. In a world where oil is scarcer, the ability of economies to produce output is decreased. This loss of ability to produce is termed a loss of potential GDP to emphasize that whether or not the economy has not been disrupted by a price shock its potential to produce is less than it would have been had oil prices been lower.

The loss of potential GDP could be measured by summing the losses (and gains) throughout the economy of producers' and consumers' surplus caused by higher oil prices. Producers' and consumers' surplus losses in the oil market are illustrated in Figure 2 by the triangular areas under the oil supply and demand curves. If oil were the only commodity produced and consumed in the U.S. economy that would be the end of it. In reality, an increase in the price of oil affects the prices of many other commodities, especially forms of energy that can be substituted for petroleum. These price increases will cause consumers' and producers' surplus losses in other markets, multiplying the losses in the oil market itself.

In this study, potential GDP losses are estimated based on the surplus losses in the U.S. oil market. First, the sum of consumers' and producers' surplus losses in the U.S. petroleum market is calculated. Recognizing that surplus losses will occur in related markets, especially in energy markets, a multiplier is used to convert petroleum market losses into an estimate of economy-wide losses.[5] In this section, the formulas for producers' and consumers' surplus losses are derived. The derivations are identical except for the sign of the result, as explained below.

Producers' and Consumers' surplus losses for dynamic, lagged adjustment supply and demand functions can be calculated by integrating under the curves with respect to the weighted sum of past and current oil prices. It is not appropriate to integrate simply with respect to the current price, because the entire history of prices affects the current levels of supply and demand. To find the appropriate price variable, we expand the lagged adjustment model by continuously substituting for the lagged dependent variable, Q_{t-1} .

$$Q_t = \lambda a_t + \lambda b P_t + (1-\lambda)Q_{t-1} = \lambda(a_t + bP_t) + (1-\lambda)\left(\lambda(a_{t-1} + bP_{t-1}) + (1-\lambda)Q_{t-2}\right) = \\ = \lambda\sum_{i=0}^{t-1}(1-\lambda)^i a_{t-i} + \lambda b\sum_{i=0}^{t-1}(1-\lambda)^i P_{t-i} + (1-\lambda)^t Q_0 \tag{1}$$

The intercept, a_t , is indexed by t to indicate that factors other than the price of oil have been changing over time and affecting the level of demand (or supply). The a_t are unobserved, but the weighted sum of the a_t's plus the lagged effect of Q_0 can be calculated using Q_t , b, λ, and the historical prices. Let K_t be the sum of the other effects in year t based on historical prices, and k_t represent the effects assuming a competitive oil price of P_0.

$$K_t = Q_t - b\lambda\sum_{i=0}^{t-1}(1-\lambda)^i P_{t-i} = \lambda\sum_{i=0}^{t-1}(1-\lambda)^i a_{t-i} + (1-\lambda)^t Q_0 \qquad and \qquad k_t = Q_t - b\lambda\sum_{i=0}^{t}(1-\lambda)^i P_0 \tag{2}$$

Next, a weighted-sum price variable, Π, can be defined to represent the cumulative effects of current and past prices on demand (or supply).[6]

[5] A very rough estimate of the oil market losses multiplier was derived by observing that over the past 30 years the prices of natural gas, electricity and coal are correlated 0.62, 0.76 and 0.77 with the price of oil, respectively. Summing total expenditures on each energy type including oil weighted by the respective correlation with the price of oil, and dividing by expenditures on oil gives an estimated multiplier of 2.3. Expenditures on natural gas and coal used to produce electricity are excluded from the calculation. This method is equivalent to assuming that the elasticity of potential GDP loss with respect to the price of each form of energy is proportional to expenditures on that fuel relative to total GDP, and that the derivative of the price of each fuel with respect to the price of oil is equal to the correlation between each fuel's price and the price of oil. This is admittedly a very rough approximation that deserves refinement.

[6] The authors are grateful to their colleague, Paul Leiby, for suggesting this simple means of averaging historical prices.

$$\Pi_t = \lambda P_t + (1-\lambda)\Pi_{t-1} = \lambda \sum_{i=0}^{t-1} (1-\lambda)^i P_{t-i}$$
$$and \quad \Pi_{ct} = \lambda P_{ct} + (1-\lambda)\Pi_{ct-1}$$
$$and\ if\ P_c\ is\ constant, \Pi_c = \lambda P_c + \lambda \sum_{i=0}^{t-1} (1-\lambda)^i P_c = P_c$$

(3)

With these definitions the demand or supply function for petroleum can be written as a function of the weighted average of past prices, Π, and integrated from any arbitrary alternative price series (including constant price, $P_c \rightarrow \Pi_c$) to the actual price series, Π_t . Consumers' surplus is the area under the demand curve from Π_c to Π_t , minus the change in expenditures calculated using Πs instead of actual prices. Producers' surplus is the change in revenues minus the area under the supply curve from Π_c to Π_t .

$$\begin{aligned}
Surplus^* &= \int_{\Pi_c}^{\Pi_t} (K_t + b\Pi) d\Pi - Q_t(\Pi_t - \Pi_c) = (K_t\Pi + \frac{1}{2}b\Pi^2)\Big|_{\Pi_c}^{\Pi_t} - Q_t(\Pi_t - \Pi_c) \\
&= \left(K_t\Pi_t + \frac{1}{2}b\Pi_t^2 - K_t\Pi_c - \frac{1}{2}b\Pi_c^2 \right) - Q_t(\Pi_t - \Pi_c) \\
&= \left[K_t + \frac{1}{2}b(\Pi_t + \Pi_c) - Q_t \right](\Pi_t - \Pi_c) \\
&= \left[Q_t - b\Pi_t + \frac{b}{2}\Pi_t + \frac{b}{2}\Pi_c - Q_t \right](\Pi_t - \Pi_c) \\
&= -\frac{b}{2}(\Pi_t - \Pi_c)^2 = -\frac{1}{2}((Q_t - K_t) - (Q_c - K_c))(\Pi_t - \Pi_c) \\
&= -\frac{1}{2}(Q_t - Q_c)(\Pi_t - \Pi_c) \quad if \quad K_t = K_c
\end{aligned}$$

(4)

This is directly analogous to the familiar surplus triangle under the demand (or supply) curve defined over the Π axis (Figure 3).[7]

This surplus measure will be in dollars, since the variable of integration, Π, is a convex combination, i.e., a weighted average of past prices.

The key uncertainties regarding this method are (1) the potential GDP loss multiplier, (2) the price elasticities (price slopes) of supply and demand, and (3) the lagged adjustment rate parameters (λ_{demand} , λ_{supply}). Estimates of these parameters are reviewed in the next chapter.

[7] The final step in equation (4) requires the assumption that $K_t = K_c$. This implies that the factors other than price affecting demand over time would have evolved in the same way under either price trajectory. By using the formula $-½b(\Pi_t - \Pi_c)^2$ instead, this assumption is not necessary.

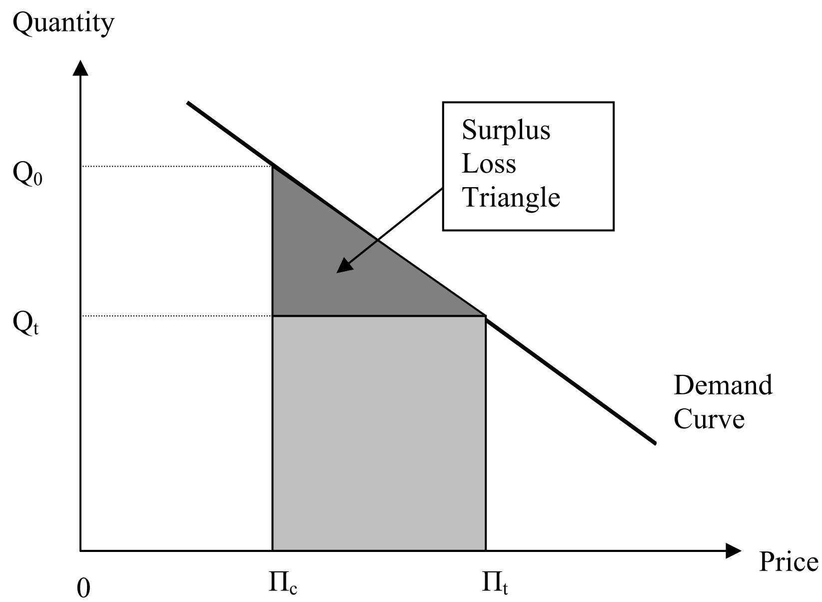

Figure 3. Estimation of Surplus Loss by Integrating Demand Curve over Weighted Price Variable

3.2.3 Macroeconomic Adjustment Costs

The simple notion of macroeconomic adjustment costs is that they arise when a sudden price shock throws the economy out of equilibrium, wages and prices are not able to adjust rapidly enough, and underemployment of labor and capital results. Over the past decade there have been important contributions to understanding the specific mechanisms by which price shocks affect the economy. Analysis of detailed sectoral job creation and destruction (Davis and Haltiwanger, 2001) has shown that oil price shocks result in more destruction than creation and have about twice the impact of monetary shocks. Furthermore, the increase in unemployment due to an oil price increase is about ten times larger than the decrease in response to a drop in price.

Rotemberg and Woodford (1996) and Huntington (2002) have produced simulations that illustrate how market power in the economy can magnify the economic impacts of oil price shocks by permitting producers to increase prices beyond the levels that perfect competition would allow (Jones et al., 2004). Huntington (2002) notes that in an economy with substantial imperfect competition, the impacts of oil price shocks are magnified because, (1) the economy begins at a position where prices exceed marginal costs and moves to a new position in which prices exceed marginal costs by an even greater amount, thereby adding to the welfare losses, and (2) the economy-wide effect of the higher noncompetitive prices is to reduce aggregate demand, a fact not considered by any individual firm and therefore a pecuniary externality and a source of additional economic inefficiency.

The dynamic adjustment of GDP to oil price shocks is a key issue in estimating macroeconomic adjustment costs. The empirical literature reflects several attempts to formulate price measures that can simultaneously represent (1) the different effects of both macroeconomic and potential GDP effects, and (2) the economy's dynamic responses to constantly changing oil prices. The first problem is addressed in this study by calculating potential GDP and macroeconomic costs separately. Potential GDP losses are calculated as the consumers' and producers' surplus losses under dynamically adjusting oil supply and demand curves, as explained in detail in Section 3.3 above. Macroeconomic adjustment costs are estimated by means of oil price elasticities of GDP. The two processes have different dynamic responses to oil price changes and can even have different signs. For example, a sudden drop in oil prices will cause macroeconomic adjustment losses and offsetting potential GDP gains.

The dynamic adjustment of macroeconomic costs to price shocks is simulated by comparing the actual price of oil in year t to the price to which the economy has adjusted by year t, given the history of oil prices. A key premise of the concept of macroeconomic costs is the economy cannot respond immediately to sudden, large price changes. Constantly changing oil prices imply that the economy is continually out of equilibrium with current oil prices. Thus, it should not be the change in the price of oil from the previous year that determines the macroeconomic adjustment impact, but rather the difference between the current price and the price to which the economy has become adjusted in the current year.

The "adjusted prices" used to estimate macroeconomic costs are derived from the concept of the linear lagged adjustment model in which the observed change in a dependent variable from t-1 to t, $X_t - X_{t-1}$, is assumed to be some fraction, $1>\lambda>0$, of the difference between the ideal, long-run level at price P_t, x_t, and last period's actual demand.

$$\begin{aligned} X_t - X_{t-1} &= \lambda\left(x_t - X_{t-1}\right) \\ x_t &= a + bP_t \end{aligned} \tag{5}$$

Substituting the second equation into the first and solving for X_t, one gets the familiar lagged adjustment demand equation.

$$X_t = \lambda a + \lambda b P_t + (1-\lambda) X_{t-1} \tag{6}$$

Long-run demand is a function of the price level, P_t, sensitivity to price represented by the parameter b, and other factors represented by a.[8] Another way of interpreting the lagged adjustment model is that for the current value of X_t there exists a price, p_t, such that X_t is the long-run equilibrium level for p_t. Substituting p_t for P_t in the second equation of (5), noting that at p_t, $x_t = X_t$, setting the resulting expression equal to equation (6) and noting that $X_{t-1} = a + bp_{t-1}$, produces the following intuitive result.

$$\begin{aligned} a + bp_t &= \lambda a + \lambda b P_t + (1-\lambda)\left(a + bp_{t-1}\right) \\ p_t &= \lambda P_t + (1-\lambda) p_{t-1} \end{aligned} \tag{7}$$

The current adjusted price is a weighted average of the current period's actual price and last period's adjusted price. A starting value for the adjusted price must be chosen, p_o, but since oil

[8] Allowing other factors to vary over time leads to a more complicated formula for the "adjusted price." If other factors are changing slowly, year-to-year price changes are large, and adjustment is relatively rapid, the simplified formula should be a reasonable approximation.

prices were quite stable prior to 1973 it should be a reasonable approximation to assume that $p_0 = P_{1972}$.

3.3 ISSUES IN ESTIMATING ECONOMIC COSTS

The literature of energy economics has addressed the relationship between the price of oil and the GDP at length. Three key issues for estimating the costs of oil dependence addressed in this literature are: (1) the size of oil price's impact on U.S. GDP, (2) whether this impact has been changing over time, and (3) how to define a price shock. There should be little controversy about whether oil price shocks reduce U.S. GDP. Jones et al. (2004) comprehensively reviewed the recent literature on whether and how oil prices affect the economy, with particular attention to the mechanisms through which oil price shocks affect GDP, the effects of monetary policy, and the stability and magnitude of the oil price-GDP relationship. They concluded that post oil shock recessionary movements of GDP are primarily due to the oil price shocks themselves and not changes in monetary policy made to accommodate the shocks. Empirical research has shown that substantial reallocation of labor occurs after an oil price shock. The costly processes by which factors must be reallocated among industries appears to be a key cause of short-lived negative impacts of price shocks. Based on their comprehensive review of the literature Jones et al. (2004) put forward -0.055 as the best consensus estimate of the elasticity of GDP with respect to a price shock, where a shock is defined as a price increase that exceeds a three-year high.

The elasticity of GDP with respect to the price of oil is a useful summary measure of the sensitivity of the economy to oil price shocks. Statistical estimates of the relationship between GDP and oil price depend to a degree on how researchers define an oil price shock. The earliest studies simply used the price of oil. Over time, researchers discovered that the economy responded asymmetrically to oil price increases and decreases, which contributed to instability in the relationship between GDP and oil prices over time. Mork (1989) offered the first asymmetric specification of an oil price shock by using different variables to represent price increases and decreases. Lee, Ni and Ratti (1995) used a measure of the surprise content of the oil price change, which they believed yielded a stable oil price-GDP relationship. Their measure divided the change in oil price by an index of the recent volatility of oil prices, thereby diminishing shocks occurring in a period of volatility. Hamilton (1996) created a new variable he called the Net Oil Price Increase (NOPI), defined as the difference between the percent increase in a current period and the highest percent increase in the previous four quarters. Hamilton and Herrera (2001) found that both Lee, Ni and Ratti's measure and NOPI had stable relationships with GDP over time, but that the simple price of oil and Mork's measure did not.

In our view, the asymmetric response of the economy to oil price changes is largely if not entirely due to the two different mechanisms by which oil prices affect GDP: (1) loss of potential GDP, and (2) macroeconomic adjustment costs.[9] The first type of cost is incurred whenever oil prices are raised above competitive market levels. The second occurs only in the event of a price shock. When there is a sudden, unanticipated price increase, both types of cost have a negative impact on the economy. When prices suddenly fall the economy benefits from an increase in potential GDP and a reduction in the transfer of wealth but still suffers adjustment costs. The

[9] The transfer of wealth will not necessarily have a negative impact on U.S. GDP. This will depend on whether the outflow of wealth reduces final demand for U.S. output, either permanently or temporarily.

positive effect may substantially or entirely offset the negative effect of the (downward) price shock. As Huntington (2002, pp. 5-6) has put it, "If both positive and negative energy price shocks create short-run unemployment as resources shift from one sector to another, these shifts between sectors could dampen and even eliminate the otherwise positive effect resulting from a sudden energy price decline." Moreover, the dynamics of the two types of costs are different. The adjustment to a price shock may occur over a period of 3 or more years as wages and prices adapt. But adjustment of the economy's capital stock of energy using equipment takes 10 years and often much longer. As a consequence, there should not be a simple, stable relationship between the GDP and a fluctuating price of oil. As will be seen below, modeling each component separately allows for complex patterns of response.

Figure 4 shows the relationship between the current price of oil and the macroeconomic "adjusted price", assuming $\lambda = 0.33$. Even in the first year of a price shock (e.g., 1974), some adjustment occurs, so that the difference between the current price and the adjusted price is somewhat smaller than that between the current price and the previous year's price. However, in the year after the price shock (1975) there is still a substantial difference between the current price and the adjusted price although there is almost no difference between the actual price in 1975 and the actual price in 1974. Interestingly, the small price shock in 1990 would have no immediate macroeconomic effect since the adjusted price equaled the current price in that year. A much more slowly adjusting price path with $\lambda = 0.15$ is also shown in Figure 4. This path is indicative of the rate at which potential GDP losses adjust to price changes.

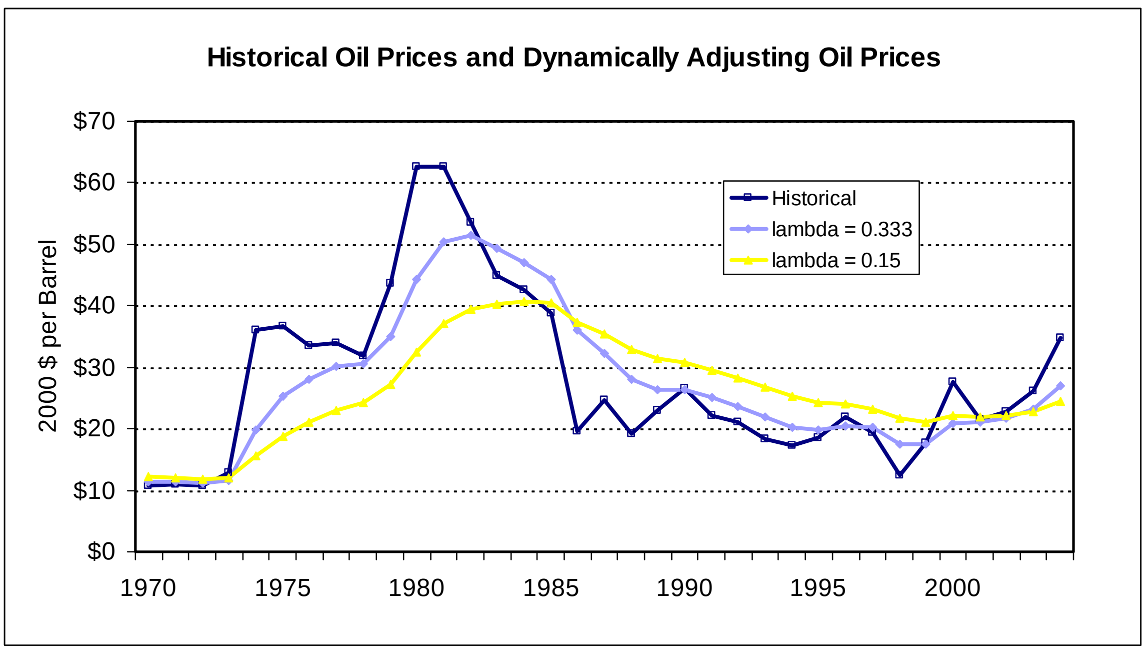

Figure 4. Historical Oil Prices and Dynamically Adjusting Oil Prices

The dynamics of all three cost components can be seen by comparing the two price paths shown in Figure 4 with the cost impacts graphed in Figure 5. When oil prices first jumped in 1973, the transfer of wealth and macroeconomic shock components responded immediately, peaking in 1974, the second year of the shock. Although the macroeconomic cost adjustment is relatively rapid, there are large differences in the initial years of the price shock. The potential GDP component responds much more slowly because it is a function of the difference between the competitive market price and the price to which the entire productive capital of the economy has adjusted. Because capital turnover is a much slower process, the loss of potential GDP is quite small in the first two years of the first price shock. In 1986, when oil prices fell from $40/bbl to $20/bbl, potential GDP losses decreased while macroeconomic costs increased. The result is almost no change in the sum of the two GDP impacts from 1985 to 1987. To observers watching the change in GDP from one year to the next, the downward price shock would appear to have had no impact at all. The interactions of macroeconomic adjustment costs and potential GDP losses produce more complex responses to oil price changes than would a simple oil price elasticity of GDP. These complex, dynamic responses are consistent with the types of responses represented in the more recent econometric studies of this subject (Jones et al., 2004).

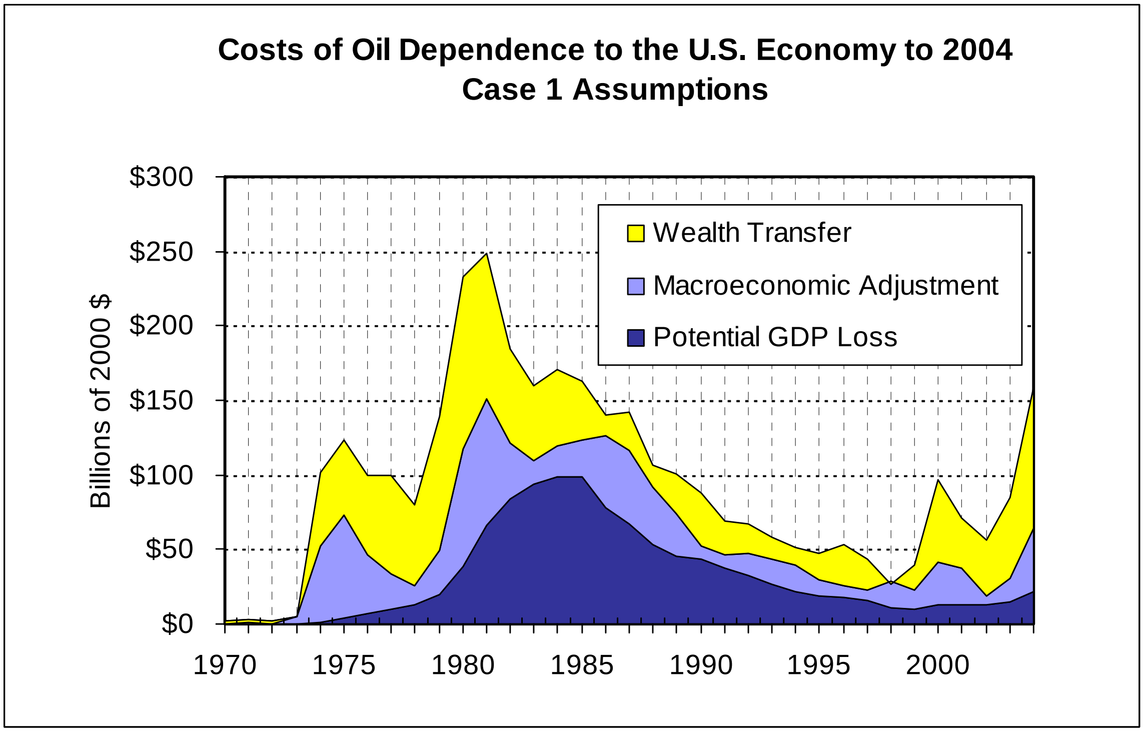

Figure 5. Estimated Costs of Oil Dependence: Case 1a Assumptions

4. UPDATING THE DATA AND METHODOLOGY

In this section four changes to the cost estimation methods used in our previous studies are explained in detail: (1) the inclusion of stochastic price paths for competitive oil prices, (2) a change in the pattern of macroeconomic adjustment costs over time to better approximate the predictions of macroeconomic models, (3) the updating of data and key parameter values based on recent evidence (the key parameters are: (a) the oil price elasticity of GDP, (b) the price elasticity of U.S. oil demand, (c) the demand adjustment rate, (d) the price elasticity of U.S. oil supply, and (e) the supply adjustment rate), and (4) the use of Monte Carlo simulation to describe uncertainties and perform sensitivity analysis.

4.1 STOCHASTIC PRICE PATHS

Estimating the costs of oil dependence by comparing historical prices to a hypothetical competitive market price of oil is a key premise of this analysis. But this premise raises the difficult question of what path oil prices might have taken in a "contrary-to-fact" competitive oil market. In previous assessments, historical oil prices have been compared to a constant, competitive market price. Given the uncertainties of world oil supply and demand and the inelasticity of both in the short run, it may seem unreasonable to assume there would be no price volatility even in a competitive market. Intuition suggests that the actual history of world oil prices might be better compared to a stochastic price path that allows for a certain degree of volatility.

In the simulations below, historical world oil prices are compared both to a constant competitive price and to time-varying prices generated by a stochastic model with first-order autocorrelation with and without a trend. For any particular stochastic price path the estimated costs of oil dependence could be higher or lower than the constant price path, depending on whether the hypothetical price series is negatively or positively correlated with the historical price shocks. When there is no trend in the stochastic price path the variability of cost estimates should increase but not their expected values.

A plausible stochastic price model can be constructed in the following way. Let P_t be the price of oil in year t, $\overline{P}$ be the average competitive price of oil, ρ be a correlation coefficient, and δ a drift (or trend) coefficient. Let ε_t be a random error term distributed N(0,σ), where σ = s×P, s being a standard deviation divided by its mean. The following model is used to generate a different price series for each stochastic price simulation.

$$P_t = \overline{P} + e_t + \delta t \qquad \text{and} \qquad e_t = \rho e_{t-1} + \varepsilon_t \tag{8}$$

Although it cannot be asserted that the recent historical record contains any period during which world oil prices were indisputably produced by competitive market forces, there are periods during which OPEC's influence was substantially diminished. Historical prices over the period 1987-2003 were used to estimate the standard deviation (σ) of price relative to the mean price, $\overline{P}$. This produced estimates of 0.24 for ρ and \$3.75 for the standard deviation of P_t, 18% of the mean price of \$21.20 from 1987-2003. In the simulations below, we use ρ = 0.25 and σ equals

0.18 times the assumed competitive market price of oil. The period 1987-2003 includes the oil price shock associated with the first Persian Gulf War.

A sample of alternative price paths produced by this stochastic model is shown in Figure 6. Three price paths, labeled stochastic + drift, are independent realizations of the stochastic model of equation 1, assuming an upward drift in prices at the rate of $0.25/bbl/year. The upward drifting price path without random components is shown, labeled deterministic drift. A stochastic price path without drift is also shown, and all can be compared to a constant price of $13/bbl. As will be seen in the results below, assuming stochastic prices without drift has little impact on the estimated costs of oil dependence, as expected.

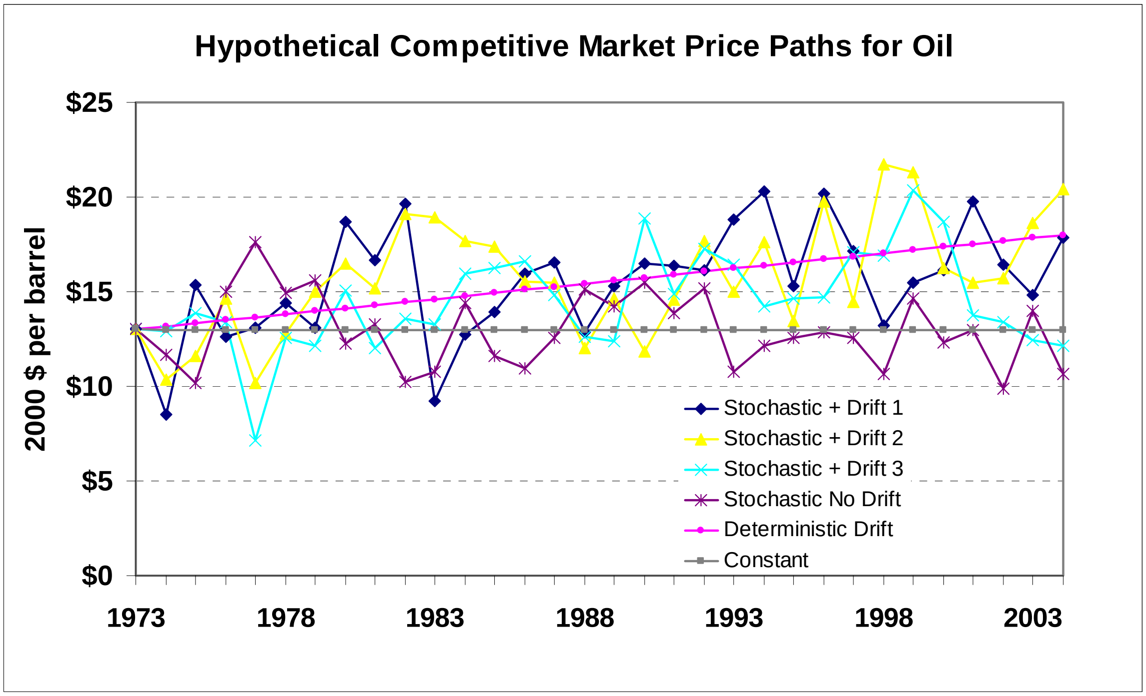

Figure 6. Stochastic Paths for the Competitive Price of Oil

In the simulations below we have assumed both upward and downward oil price drift are possible. On the one hand, it can be argued that the depletion of oil resources should lead to an upward drift in oil prices, either because of the Hotelling resource exhaustion effect or because of an increasing level of effort required to produce from increasingly depleted or more difficult to access deposits. But as several have pointed out, such a trend runs counter to much of the historical experience with mineral resources (e.g., Watkins, 1992; Adelman and Lynch, 1997). In most cases, it appears that technological progress outpaces depletion, leading to decreasing not increasing mineral resource costs over time. Certainly there is ample evidence of technological progress in oil discovery and production (e.g., Alazard, 1996). Thus, there appears to us to be no compelling reason to believe that declining competitive oil prices is a less reasonable assumption than upward drifting oil prices.

4.2 TIMING OF MACROECONOMIC IMPACTS

Macro-economic models used to estimate the impacts of oil price shocks on GDP generally predict a greater impact in the year following the initial price shock than in the year in which the shock actually occurs. According to Jones et al. (2004, p. 13)[10], "…virtually all empirical studies have found the largest impacts of oil prices on output in the 3rd and 4th quarters, and continued effects in later quarters." This appears to be the result of various lags in the economy's response to oil price changes. For some models, impacts then decay in succeeding years. The energy modeling forum compared the predictions of GDP impacts from 14 different macroeconomic models, given a 50% increase in oil price starting in 1983 and persisting indefinitely (Hickman, 1987). The majority predicted a substantially greater impact in the second year of the price increase (Figure 7).

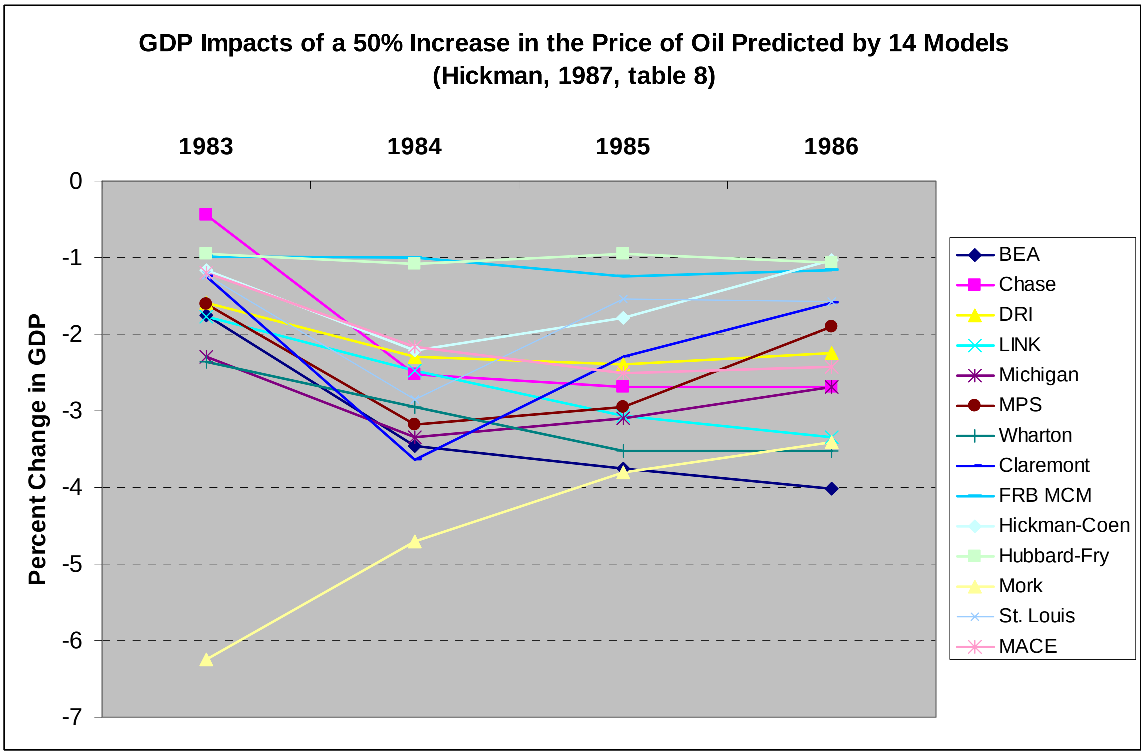

Figure 7. Distribution of Oil Price Impacts on GDP over Four Years

It is important to keep in mind that these models are representing, in theory, the combined macroeconomic adjustment and potential GDP effects. Since we are estimating potential GDP losses independently, only a fraction of the total GDP elasticity should be attributed to macroeconomic costs. However, because oil supply and demand adjusts more slowly than wages and prices, the majority of the oil price impact in the first few years will be due to macroeconomic adjustment costs. In the simulation below we assume that 75% of the maximum, initial GDP impact is due to macroeconomic adjustment costs. Thus, if the overall maximum GDP elasticity is judged to be -0.055, then the maximum macroeconomic adjustment cost elasticity will be -0.04.

[10] The literature review by Jones et al. (2004) did not include Santini (1994) which also found that energy prices affect GDP most strongly with a 1-year lag.

A simple average of the model predictions shown in Figure 7 indicates a first-year impact of -1.77% followed by a -2.71% loss of GDP in the second year (Figure 8). The medians of the estimated first- and second-year impacts are -1.42% and -2.69%, respectively. Thus, the models tend to predict that somewhere between half and two-thirds of the maximum second year impact is felt in the first year.

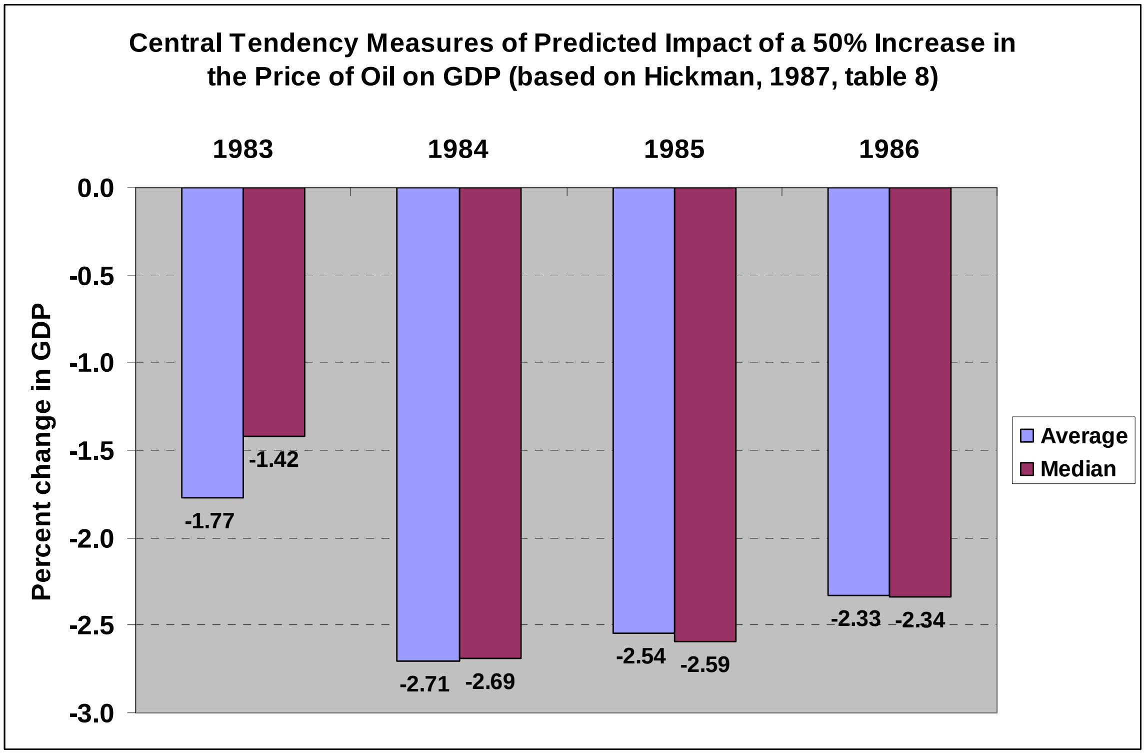

Figure 8. Average Predicted Impacts of Oil Price on GDP over Four Years

The cost estimation methodology has been modified to reflect the lagged behavior exhibited by the majority of models tested by Hickman (1987). The new equation for the oil price elasticity of GDP is the following (abs( ) indicates the absolute value function).

$$MAC = \lambda \left[abs\left(1 - \left(\frac{P_t}{p_t} \right)^{0.75\beta\left(\frac{\phi_t}{\phi_{1983}}\right)} \right) GDP_t \right] + (1-\lambda)\left[abs\left(1 - \left(\frac{P_{t-1}}{p_{t-1}} \right)^{0.75\beta\left(\frac{\phi_{t-1}}{\phi_{1983}}\right)} \right) GDP_{t-1} \right] \tag{9}$$

In equation (9) β is the second-year, maximum oil price elasticity of GDP, φ_t is the oil cost share of GDP in the current year (φ_{1983} is the reference year in which β is assumed to apply), P_t is the actual price of oil in year t while p_t in the denominator is the price to which the economy has adjusted, and λ is the fraction of the maximum macroeconomic adjustment impact assumed to occur in the first year. The data presented above suggest that λ is approximately 0.55.

In equation (9) price shocks in opposite directions in succeeding years would not cancel each other; both would have a disruptive effect on the economy. There is also no threshold effect. A very small price movement would have a very small negative effect. For example, a 10%

increase in oil price occurring in 2003 (when the oil cost share of GDP was 1.9% compared with 4.6% in 1983, so that the effective elasticity would be (1.9/4.6) 0.75 (-0.055) = -0.17 instead of -0.055) would cause a loss of 0.1% = $0.55*(1-(1.1^{-0.017}))$ of GDP in that year. The 2003 price shock would also have a lagged effect in the following year of almost the same amount.

Given this new method, the maximum GDP impact should be based on the second year estimates of the fourteen models. Since the estimates shown in Figures 7 and 8 are based on a 50% increase in oil prices, an estimate of price elasticity would be double these values, or about -0.054. Recent empirical evidence on the oil price elasticity of GDP is considered in the following section.

4.3 RECONSIDERING KEY PARAMETERS

In this section, recent empirical evidence on the values of five critical parameters is reviewed.

4.3.1 The Oil Price Elasticity of GDP

In a previous study (Greene & Tishchishyna, 2001) the elasticity of GDP with respect to the price of oil was assumed to be -0.046. This estimate is the median of the predictions of fourteen models reported in a study by the Energy Modeling Forum for the period 1983-1986, shown here in Table 1. It also includes all four years of predictions, not just the maximum impact in year 2. The mean and median of the estimates for year 2 is -0.054. Given the decreasing consumption of oil per dollar of GDP over time, one might expect more recent estimates to be smaller in absolute value. However, an elasticity of -0.055 was judged to be a consensus of the recent literature by Jones et al. (2004).

Table 2 shows the elasticities from six recent studies included in the Jones et al. (2004) review. Huntington's 1998 and 2002 analyses of crude oil prices and U.S. economic performance (not included in Jones et al., 2004) also report estimates of the oil price-GDP elasticity. Perhaps the most significant implication of these recent studies is the lack of evidence of a decreasing vulnerability to oil price shocks over time. The estimates derived from 14 models by Hickman (Table 1) indicate an oil price elasticity of GDP of -0.054 (based on 2nd year mean or median impact) for the period 1983-1986. The more recent estimates presented in Table 2 are of the same general magnitude. Thus, the recent empirical literature tends to contradict the intuitively appealing concept that the vulnerability of the economy to oil price shocks has decreased as the amount spent on oil has decreased relative to the GDP.

Despite the contradictory evidence from empirical studies, we still believe that the vulnerability of the economy to oil price shocks should be relatively smaller today than it was during the 1970s and 1980s (e.g., Parry and Darmstadter, 2003, p. 3; Brown and Yücel, 2002).[11] Because of the many complex factors that determine the impact of oil prices on the economy, there is no simple theory that can be applied to decide the question. It seems clear that if the economies of the world consumed almost no oil, the impact of an oil price shock on output would be

[11] The Energy Information Administration's (US DOE/EIA, 2004a) "Rules of Thumb for Oil Supply Disruptions" specifies a 0.05 to 0.1 percent decline in real GDP for each 10% increase in the price of oil, an implied elasticity range of -0.005 to -0.001. This is only one tenth to one fifth of the literature-based estimates perhaps indicating a belief that the economy's sensitivity to oil prices has decreased dramatically.

approximately zero. The question is then what path the elasticity may take between a value of -0.055 and zero as oil consumption decreases to zero.

Table 1. Estimates of Elasticity of GNP with Respect to Oil Price (50% Price Shock, Effect on Real GNP)

	Percent Change in Real GNP			
MODEL	1983	1984	1985	1986
BEA	-1.754	-3.463	-3.754	-4.012
Chase	-0.438	-2.531	-2.686	-2.682
DRI	-1.585	-2.298	-2.398	-2.246
LINK	-1.767	-2.480	-3.071	-3.339
Michigan	-2.297	-3.340	-3.106	-2.692
MPS	-1.606	-3.174	-2.946	-1.900
Wharton	-2.363	-2.949	-3.518	-3.524
Claremont	-1.253	-3.638	-2.289	-1.589
FRB MCM	-0.981	-1.001	-1.252	-1.160
Hickman-Coen	-1.171	-2.215	-1.780	-1.034
Hubbard-Fry	-0.954	-1.080	-0.957	-1.058
Mork	-6.243	-4.709	-3.809	-3.406
St. Louis	-1.224	-2.847	-1.540	-1.578
MACE	-1.192	-2.159	-2.501	-2.426
Average	*-1.77*	*-2.71*	*-2.54*	*-2.33*
Ratio to Yr 2	0.66	1.00	0.94	0.86
Median	*-1.419*	*-2.689*	*-2.594*	*-2.336*
Ratio to Yr 2	0.53	1.00	0.96	0.87
Lower Quartile	*-1.18*	*-2.24*	*-1.91*	*-1.58*
Ratio to Yr 2	0.53	1.00	0.85	0.71

Source: (Hickman, B.G., 1987, table 8)

Table 2. Recent Estimates of the Elasticity of GDP with Respect to the Price of Crude Oil

Study	Estimate
Mory (1993)	-0.055
Mork et al. (1994)	-0.054
Hamilton and Herrera (2001)	-0.055 over 42 months
Bernanke et al. (1997)	-0.027 over 18 months
Hamilton (2003)	-0.116 using 3-year NOPI shock measure, over 8 quarters
	-0.054 using the LNR shock measure
Huntington (1999)	-0.110
Huntington (2002)	-0.040
U.S. Dept. of Energy	-0.025 to -0.055

Source: Jones et al. (2004)

In previous reports, the maintained hypothesis has been that the oil price elasticity of GDP is proportional to total expenditures on oil divided by GDP (the "oil cost share" of GDP, shown in Figure 9). Mitigating factors, such as the concentration of oil use in the transportation sector and increased market power in other sectors of the economy (Huntington, 2002, makes an impressive case for this effect) might offset the effect of a smaller oil expenditure share, at least over some range. Add to this possibility the fact that the empirical evidence supports this conclusion and one must also admit the possibility of an approximately constant oil price elasticity of GDP over the past 30 years. For this reason, we have adopted a new maintained hypothesis that gives equal probability to constant elasticity versus elasticity scaled by the oil expenditure share of GDP.

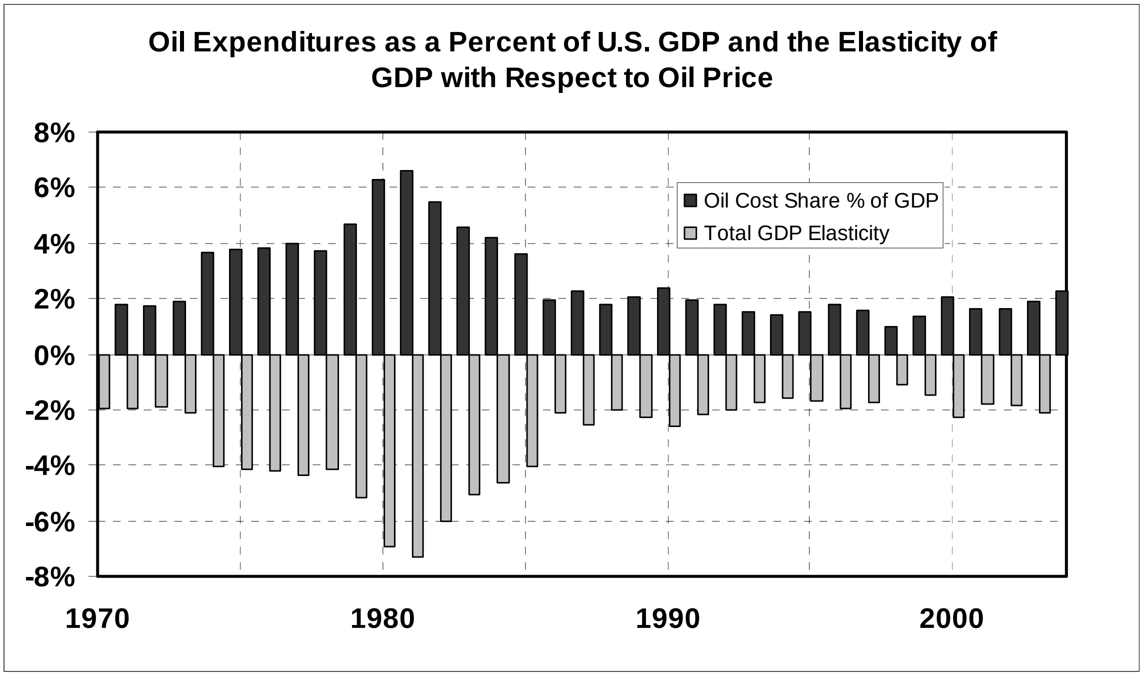

Figure 9. Total Expenditures on Oil as a Percent (Cost Share) of GDP

Because of the inelasticity of oil demand, the oil expenditure share of GDP reflects the pattern of oil prices over the past 35 years (Figure 9). In 1983, the starting date for the EMF simulations of oil price impacts shown in Table 2, the oil expenditure share of GDP was 4.6%. This fell to a low of 0.9% in 1998 and then rose to 1.5% in 2004. If the macroeconomic portion of the maximum (second year) impact of an oil price shock is taken to be 80%, then the oil price elasticity of GDP for macroeconomic adjustment costs (excluding potential GDP impacts) would be -0.05*0.8 = -0.04 in 1983. In 2004, the expenditure share adjusted oil price elasticity of GDP (for macroeconomic adjustment costs) would be a great deal smaller: -0.05*0.8*(0.015/0.046) = -0.013. This result is consistent with Brown and Yücel's (1995) assertion that the effects of price shocks on the U.S. economy may have been only one third as large in the year 2000 as when oil prices were at their height in the early 1980s. The scaling of GDP impacts by the oil expenditure share of GDP affects only macroeconomic adjustment costs, since the oil price elasticity of GDP is not used in calculating the transfer of wealth or potential GDP components.

4.3.2 Oil Supply and Demand Elasticities

Several recent studies imply that U.S. oil supply and demand elasticities may be slightly greater than assumed in our previous reports. Price elasticities of oil demand from a number of recent studies were evaluated by Atkins and Jazayeri (2004). These are summarized in Table 3. The short-run price elasticity estimates had a mean value of -0.052 and a median of -0.05. The long-run estimates showed much greater variability, but with a mean and median of -0.36 and -0.32, respectively. Assuming a linear lagged adjustment demand equation, these imply mean and median adjustment rates of 0.86 and 0.84, respectively.

Table 3. Recent Estimates of the Price Elasticity of Oil Demand

Author	Short-Run	Long-Run	Adjustment Rate	Region
Kalymon (1975)	--	-0.5	--	various
Brown and Philips (1980)	-0.08	--	--	
Dahl (1993)	-0.05 to -0.09	-0.16 to -0.23	0.6 to 0.7	various
Peseran, et al. (1998)	-0.03	-0.48	0.9	
Gately & Huntington (2002)	-0.05	-0.59 to -0.64	0.9	OECD
Gately & Huntington (2002)	-0.03	-0.16 to -0.27	0.8 to 0.9	non-OECD
Cooper (2003)	0.0 to -0.11	0.0 to -0.53	0.8	23 countries
Cooper (2003)	-0.024 to -0.069	-0.18 to -0.45	0.8 to 0.9	G-7
Hunt & Ninomiya (2003)	--	-0.08 to -0.12	--	Japan, UK

Source: Cooper (2003)

Greene, Jones and Leiby (1995) found a range of estimates of short-run demand elasticities of -0.027 to -0.116, with a mean of -0.070 and a median value of -0.062. Long-run elasticities ranged from -0.16 to -2.5, with mean and median values of -0.65 and -0.54, respectively. Adjustment rates varied widely, from 0.58 to 0.99 (associated with the long-run elasticity of -2.5). The mean and median values imply an adjustment rate of 0.89. These estimates were based on oil prices averaging approximately $35 per barrel (2000 $).

Gately and Huntington (2002) compared constant elasticity demand models with models that allowed different responses to price increases and decreases. They estimated separate models for OECD and non-OECD countries. For OECD countries, the short-run elasticity of their constant elasticity model was -0.05, while their asymmetric model indicated an elasticity of -0.04 for price decreases and -0.08 for increasing prices. Tests indicated that the asymmetric model was significantly better than the constant elasticity model. The lagged adjustment coefficient estimates ranged from 0.88 to 0.91, suggesting long-run elasticities approximately ten times as large as the short-run values. Long-run elasticities were -0.59 for the constant elasticity model and -0.64 to -0.71 for two versions of the asymmetric model. Elasticities for non-OECD countries were smaller: -0.03 for the short-run elasticity in the constant elasticity model, +0.04 to -0.05 in the asymmetric model, which was not consistently a superior formulation for non-OECD countries. Lagged adjustment coefficient estimates were 0.82 to 0.84, and long-run elasticity estimates ranged from -0.16 to -0.27.

Less information is available concerning the price elasticity of oil supply. Huntington (1991) reviewed estimates of the price elasticity of oil supply outside of OPEC (Table 4). He found that short-run elasticity estimates were considerably less than +0.1, averaging +0.03 for total non-OPEC supply and +0.05 for the United States and other OECD countries. In his simulation modeling, Huntington (1994) chose a value of +0.4 for the long-run price elasticity of oil supply and an adjustment rate of 0.9, implying a short-run elasticity of +0.04. Gately (2004) assumed a short-run, non-OPEC oil supply elasticity of between 0.03 and 0.05 in his analysis of OPEC's incentives to expand production capacity. His long-run supply elasticity estimates ranged from 0.15 to 0.58, implying adjustment rates between 0.80 and 0.91.

Table 4. Estimates of the Elasticity of U.S. Oil Supply

Model/Source	Short-Run	Long-Run	
EIA	0.117	0.34	0.66
Gately	0.045	0.577	0.92
CERI	0.137	0.195	0.30
HOMS	0.012	0.522	0.98
FRB Dallas	0.013	0.475	0.97
HOMS-I	0.0859	0.662	0.87
Average	0.068	0.462	0.85

Source: Huntington, 1991, table A.3.

Linear lagged adjustment equations are used to represent U.S. oil demand and supply for purposes of calculating losses of potential GDP. The linear form implies that price elasticities are not constant over time, but vary with the price of oil and quantities consumed and produced.

$$Q_t = \lambda a + \lambda b P_t + (1-\lambda)Q_{t-1}$$

$$\frac{\partial Q}{\partial P}\frac{P}{Q} = \lambda b \frac{P}{Q} \tag{10}$$

The price elasticities given above and shown in Table 6 below are assumed to apply at the average price of oil over the period 1970-2004, \$28/bbl, and the average quantities of U.S. demand (17.5 mmbd) and supply (10.2 mmbd). Based on the evidence presented above, the short-run price elasticity of U.S. oil demand is assumed to be -0.06 at the average price of oil since 1971 (\$28/bbl) and the average level of U.S. demand (17.45 mmbd). The short-run elasticity of supply is assumed to be +0.05 at the same price and at the average U.S. oil production for 1971-2004 of 10.24 mmbd). The adjustment rates are assumed to be 0.85 for demand and supply (λ = 0.15), so that the long-run elasticities are -0.4 and +0.33, again at \$28/bbl. More elastic supply and demand implies larger potential GDP losses.

4.3.3 Updating Historical Data, 2005 Estimates

All data were updated to 2004 based on statistics available in the Energy Information Administration's Annual Energy Review 2003 and other EIA reports detailed listing of data and sources is provided in Table 5. At the time of writing, incomplete data were available for some data series for 2004. Annualized year-to-date data available on the EIA's web site were used. Depending on the data series, the ending month ranged from July to December, 2004.

Table 5. List of Data Sources

Data for 2004 - 2005

Energy Information Administration. 2005. *Short Term Energy Outlook*. <http://www.eia.doe.gov/emeu/steo/pub/pdf/feb05.pdf> February 8, 2005.

Total World Oil Production: Table 3 International Petroleum Supply and Demand: Row 'Total World Supply,' columns 'Year' 2004 and 2005

OPEC Oil Production: Table 3 International Petroleum Supply and Demand: Row 'OPEC Supply,' columns 'Year' 2004 and 2005

Net Imports: Table 5 U.S. Petroleum Supply and Demand: Row 'Total Petroleum Net Imports,' columns 'Year' 2004 and 2005

US Oil Demand: Table 5 U.S. Petroleum Supply and Demand: Row 'Total Demand,' columns 'Year' 2004 and 2005

Refiner Acquisition Costs (Imported): Table 4 U.S. Energy Prices: Row 'Crude Oil Prices – Imported Average,' columns 'Year' 2004 and 2005. Domestic and Composite prices are taken as a ratio of the Imported price.

GDP Implicit Price Deflator: Table 1 U.S. Macroeconomic and Weather Assumptions: Row 'GDP Implicit Price Deflator,' columns 'Year' 2004 and 2005

Gross Domestic Product: Table 1 U.S. Macroeconomic and Weather Assumptions: Row 'Real GDP,' columns 'Year' 2004 and 2005

Imports from OPEC: 2005 Imports assumed to be the same as 2004 levels

Data for 1970 – 2003

Energy Information Administration. 2004. "Oil Production." *International Petroleum Monthly*. <http://www.eia.doe.gov/ipm/toc.html> November 1, 2004.

Total World Oil Production:Table 1.4 World Oil Supply: Column 'World.'

OPEC Oil Production:Table 1.4 World Oil Supply: Column 'OPEC.'

Energy Information Administration, 2004. *Monthly Energy Review*. Publication DOE/EIA-0035(2004/10). Office of Energy Markets and End Use, U.S. Department of Energy. October 2004.

Net Imports: Table 1.7 Overview of U.S. Petroleum Trade: Columns 'Net Imports.'

Imports from OPEC: Table 1.7 Overview of U.S. Petroleum Trade: Column 'Imports from OPEC.' Includes 2004 average.

US Oil Demand: Table 1.7 Overview of U.S. Petroleum Trade: Column 'Products Supplied' (US Oil Demand).

Refiner Acquisition Costs: Table 9.1 Crude Oil Price Summary: Columns 'Refiner Acquisition Cost' for Domestic, Imported, and Composite.

Table 5. List of Data Sources (continued)

US Oil Production: Production = US Oil Demand – Net Imports

ROW Oil Production: Production = World Oil Production – OPEC Oil Production – US Oil Production

Energy Information Administration, 2004. *Annual Energy Review 2003*. Publication DOE/EIA-0384. Office of Energy Markets and End Use, U.S. Department of Energy. September 2004.

GDP Implicit Price Deflator: Table D1 Population and U.S. Gross Domestic Product, Selected Years, 1949-2003: Column 'US GDP – Implicit Price Deflator (2000 = 1.00000).'

Gross Domestic Product: Table D1 Population and U.S. Gross Domestic Product, Selected Years, 1949-2003: Column 'US GDP – Billion Chained (2000) Dollars.'

Discount Rate: Federal Reserve Bank of Minneapolis, "Discount Rates – Historical Discount Rate." <http://woodrow.mpls.frb.fed.us/research/data/us/disc.cfm>

4.4 MONTE CARLO SIMULATION

A fourth major change to the cost estimation method is the use of Monte Carlo simulation. Simulations were carried out using the @Risk software (Palisade, 2002). For a Monte Carlo risk analysis, the critical assumptions are the probability distributions of the key model parameters (Table 6). In general, there is scant evidence on which to base these distributions. In some cases, the range of estimates of a parameter that can be found in the literature may be a guide. The reader may compare, for example, the range assumed for the oil price elasticity of GDP with the literature estimates shown in Tables 1 and 2 above. Even in such cases there is little on which to base the shape of the distribution of values and even less to correlate one parameter's distribution with another's. Here we have followed five principles:

1. Where ample estimates are available we use them to establish a parameter's central tendency and range.
2. Where there is little evidence on the distribution of a parameter, we choose a range large enough to determine the sensitivity of the results to that parameter.
3. In all cases we have chosen triangular distributions, except that we use the binomial distribution to represent uncertainty about whether or not the oil price elasticity will be constant or scaled to oil expenditures as a share of GDP.
4. No correlations among parameters are assumed, i.e., they are considered to be independent.

Given this approach, the resulting probability distributions of cost estimates should be interpreted as conditional on our assumptions and not as revealing the true probability distribution of costs. If, on the other hand, one accepts our probability distributions as a reasonable description of uncertainty, then one should accept the resulting distribution of cost estimates as reasonably characterizing the range of uncertainty.

Five alternative cases have been analyzed. Cases 1, 1a and 1b are based on a competitive oil price that is constant over time (1970-2004) but varies from one simulation run to another according to the distribution specified in Table 6. Case 1 gives equal probability to the view that the oil price elasticity of GDP may be constant over time versus the view that it should be scaled by oil expenditures as a share of GDP. Case 1a assumes that the oil price elasticity varies in proportion to the oil cost share of GDP. Case 1b assumes a constant oil price elasticity of GDP over time. In all three cases the GDP elasticity varies over simulations according to the probability distribution specified in Table 6. Cases 2 and 2a include stochastic competitive oil price paths with no drift (Case 2) and with drift (Case 2a).

Table 6. Distributions of Key Parameters and Application in Alternative Cases

Parameter	Distribution	Case 1	Case 1a	Case 1b	Case 2	Case 2a
Oil Price Elasticity of GDP	Triang (-0.09, -0.055, -0.02)	X	X	X	X	X
Macro. Share of GDP Elasticity	Triang (0.6, 0.75 0.9)	X	X	X	X	X
1st Year Macro. Rel. to 2nd	Triang (0.45, 0.55, 0.65)	X	X	X	X	X
Macro. Cost Adj. Rate	Triang (0.222, 0.333, 0.444)	X	X	X	X	X
Constant v. Relative GDP Elast.	Binomial (0,1; p=0.5)	X	Rel.	Const.	X	X
Potential GDP Loss Adj. Rate	Triang (0.05, 0.1, 0.15)	X	X	X	X	X
Demand	Triang (0.05, 0.1, 0.15)	X	X	X	X	X
Supply	Triang (0.05, 0.1, 0.15)	X	X	X	X	X
Potential GDP Loss Multiplier	Triang (1.5, 2.25, 3.0)	X	X	X	X	X
US Oil Demand Elasticity	Triang (-0.08, -0.06, -0.04)	X	X	X	X	X
US Oil Demand Adj. Rate	Triang (0.05, 0.15, 0.25)	X	X	X	X	X
US Oil Supply Elasticity	Triang (0.03, 0.05, 0.07)	X	X	X	X	X
US Oil Supply Adj. Rate	Triang (0.05, 0.15, 0.25)	X	X	X	X	X
Mean Competitive Oil Price	Triang ($10, $13, $16)	X	X	X	-	-
Oil Price Drift (cents/yr)	Triang (9.6774, 0, -9.6774)	-	-	-	-	X
Random Price Error Correlation	Triang (0.1, 0.25, 0.4)	-	-	-	X	X

For all simulations, the Latin Hypercube method of sampling from probability distributions was used and 5,000 iterations were executed for each case. This method insures that the sensitivity of cost estimates to each parameter will be accurately estimated, provided that we have specified a reasonable range of possible values for each parameter.

5. RESULTS

The costs of oil dependence have been very large under any of the alternative cases examined. Given the reference Case 1 assumptions the total costs of oil dependence since 1973 come to $3.6 trillion (2000 constant, undiscounted dollars). Adjusted to present value, the total past costs of oil dependence exceed $8 trillion, an amount greater than the national debt ($7.5 trillion). Across the range of cases analyzed, the mean estimates of the total costs of oil dependence range from $3.3 to $3.9 trillion (2000 constant $). Total cost is relatively evenly divided between the three categories of cost. The Case 1 estimates are transfer of wealth ($1.3T), potential GDP losses ($1.0T) and macroeconomic adjustment costs ($1.2T).

5.1 REFERENCE CASE 1

The Case 1 simulation allows the competitive price of oil to vary between $10 and $16 with a mean and most likely value of $13 per barrel. Whatever competitive price is chosen for a single run remains constant from 1973 to 2004. There is no time-trend in the competitive price of oil and random oil price paths are not simulated in Case 1. All of the 10 other parameters not related to the competitive price of oil also vary, according to the distributions shown in Table 6. The cumulative, total, economic cost of oil dependence ranges between $2.7 and $4.7 trillion (a 90% sensitivity interval), with a mean value of $3.6 trillion (2000 $). The reader is reminded that this does not imply that the true economic costs lie between $2.7 and $4.7 trillion with 90% confidence, but rather that 90% of the simulation results fell within this interval (Figure 10).

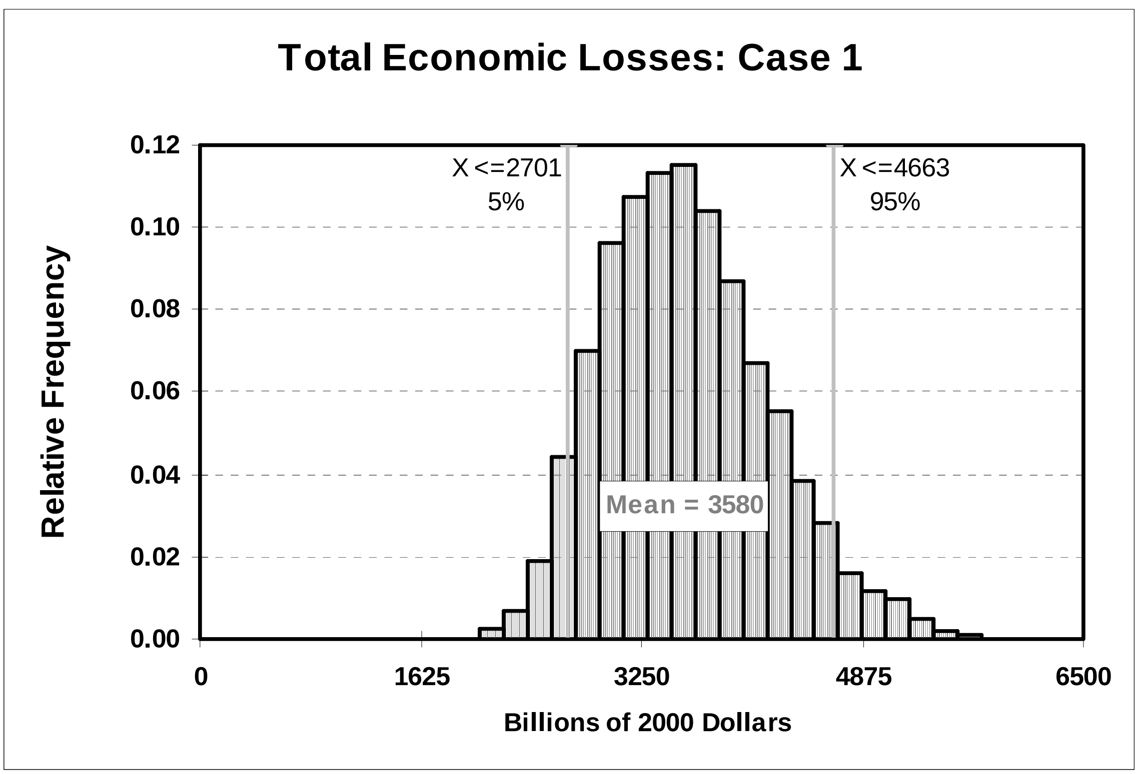

Figure 10. Total Economic Losses in the Reference Case Simulations (Case 1)

The key determinants of the estimated costs of oil dependence in Case 1 are shown in the tornado chart in Figure 11. Tornado charts graph normalized coefficients from a regression of estimated cost on the parameter values. The values at the end of the bars indicate by how many standard deviations the estimated cost will change if the input variable changes by one standard deviation. Two factors emerge as the most important, both about equally important. A one standard deviation increase in these variables results in a one-half standard deviation decrease in the costs of oil dependence (Table 7). The two are associated with the impacts of oil price shocks: (1) the value of the oil price elasticity of GDP, and (2) whether that elasticity is assumed to remain constant over time or to vary in proportion to oil expenditures as a share of GDP. A one standard deviation change in the estimated total cost is $603 billion, so a one standard deviation increase in the oil price elasticity of GDP would result in a $316 billion decrease in the total costs of oil dependence. The oil price elasticity of GDP is a negative number, so increasing it would bring it closer to zero. One standard deviation of the GDP elasticity is 0.014, which implies that an increase in the oil price elasticity of GDP from -0.055 to -0.041 would reduce total estimated costs by $316 billion. Also important is the competitive price of oil which affects all three cost components. Here one standard deviation is $1.22/bbl. Increasing the assumed competitive price of oil from $13 to $15.50 (two standard deviations) would decrease the estimated total costs of oil dependence by $480 billion.

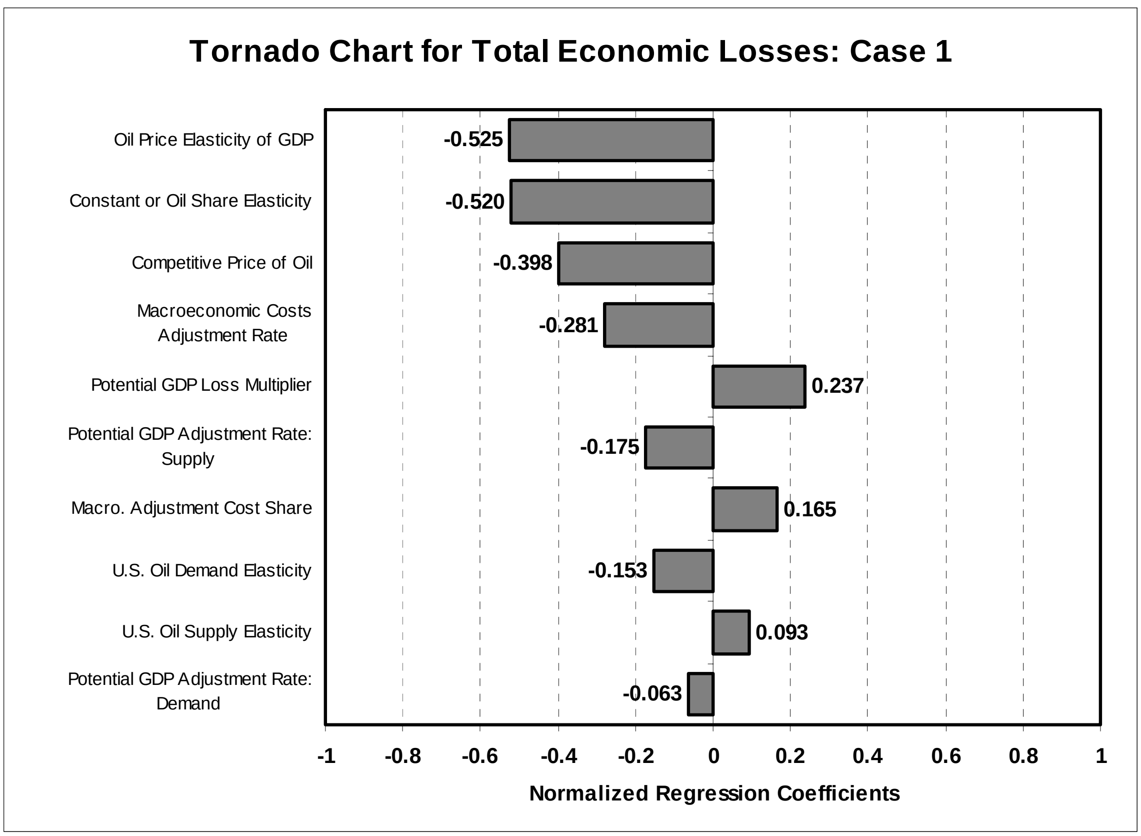

Figure 11. Sensitivity Analysis for Total Economic Costs: Case 1

Table 7. Means and Standard Deviations of Variables in Sensitivity Analysis

Variable	Billions of 2000 Dollars				
Outputs	Case 1	Case 1a	Case 1b	Case 2	Case 2a
Total Economic Losses	3580	3266	3894	3575	3576
(Standard Deviation)	(603)	(444)	(581)	(557)	(570)
Total Wealth Transfer	1312	1312	1312	1312	1312
(Standard Deviation)	(112)	(111)	(112)	(49)	(77)
Total Potential GDP Losses	1042	1040	1041	1035	1037
(Standard Deviation)	(267)	(267)	(268)	(228)	(234)
Total Macroeconomic Adjustment	1227	914	1541	1227	1226
Losses (Standard Deviation)	(503)	(286)	(476)	(504)	(501)

Inputs	Mean	Standard Deviation
Macroeconomic Adjustment Costs		
Oil Price Elasticity of GDP	-0.055	0.014
Macroeconomic Adjustment Share of GDP Elasticity	0.75	0.06
1st Year Macroeconomic Impact Related to 2nd	0.55	0.04
Macroeconomic Cost Adjustment Rate	0.333	0.045
Constant or Share-dependent Elasticity(1)	0.5	0.5
Potential GDP Losses		
U.S. Oil Demand Elasticity	-0.06	0.008
U.S. Oil Demand Adjustment Rate	0.15	0.04
U.S. Oil Supply Elasticity	0.05	0.008
U.S. Oil Supply Adjustment Rate	0.15	0.04
Consumer/Producer Surplus Multiplier	2.25	0.31
Oil Price Parameters		
Competitive Market Oil Price(2)	13.00	1.22
Oil Price Drift(3)	-0.00	0.04
Stochastic Price Error Correlation(4)	0.25	0.06

(1)Constant in Cases 1a and 1b
(2)Constant in Cases 2 and 2a
(3)Constant in all cases except 2a
(4)Constant in Cases 1, 1a, and 1b

Of lesser importance but still significant are the elasticities of oil supply and demand, and the associated rates of adjustment. Interestingly, the rates of adjustment seem to be somewhat more important than the elasticities themselves. Of somewhat less significance is the fraction of the overall oil price elasticity of GDP that is assigned to macroeconomic adjustment costs versus potential GDP loss. Changing that fraction from 0.75 to 0.6 would reduce estimated total costs by about $250 billion.

Each of the three cost components also has a distribution and can be subjected to sensitivity analysis. Macroeconomic adjustment costs have a mean of $1.2 trillion and a 90% simulation interval of $0.6 to $2.2 trillion. The distribution is skewed to the right, with some cost estimates exceeding $3 trillion (Figure 12).

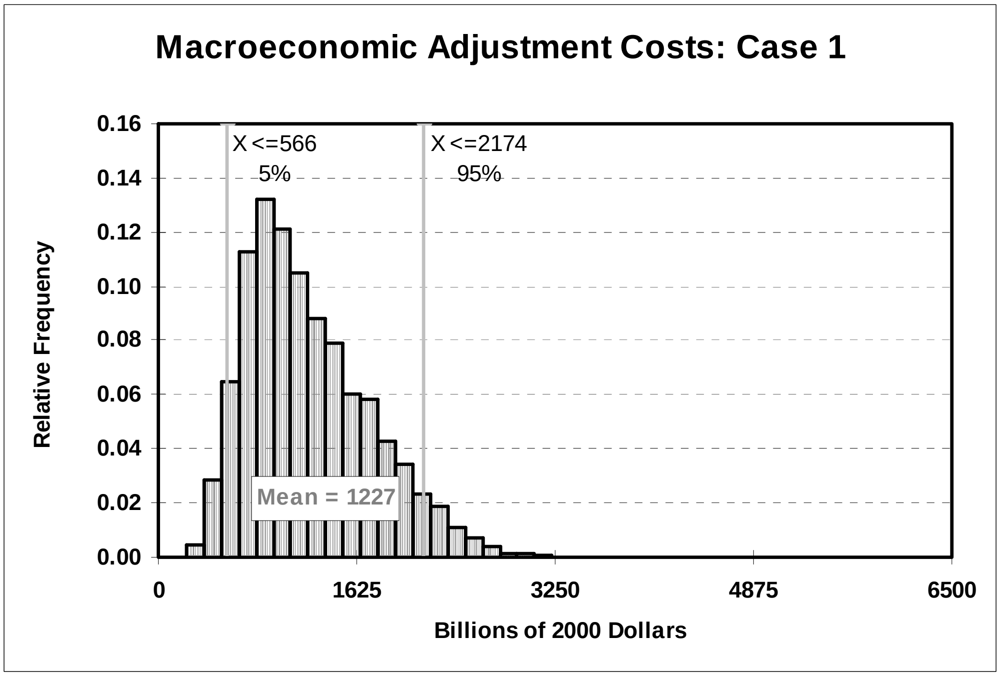

Figure 12. Frequency Distribution of Macroeconomic Adjustment Costs: Case 1

Macroeconomic adjustments costs are sensitive to only a few factors: (1) the oil price elasticity of GDP, (2) whether that elasticity is constant or varies with the oil cost share, (3) the rate of adjustment to oil price shocks, and (4) the fraction of the total GDP elasticity ascribed to macroeconomic adjustment costs (Figure 13). Because losses of potential GDP are estimated by areas under the oil supply and demand curves, the oil price elasticity of GDP affects only macroeconomic adjustment costs.

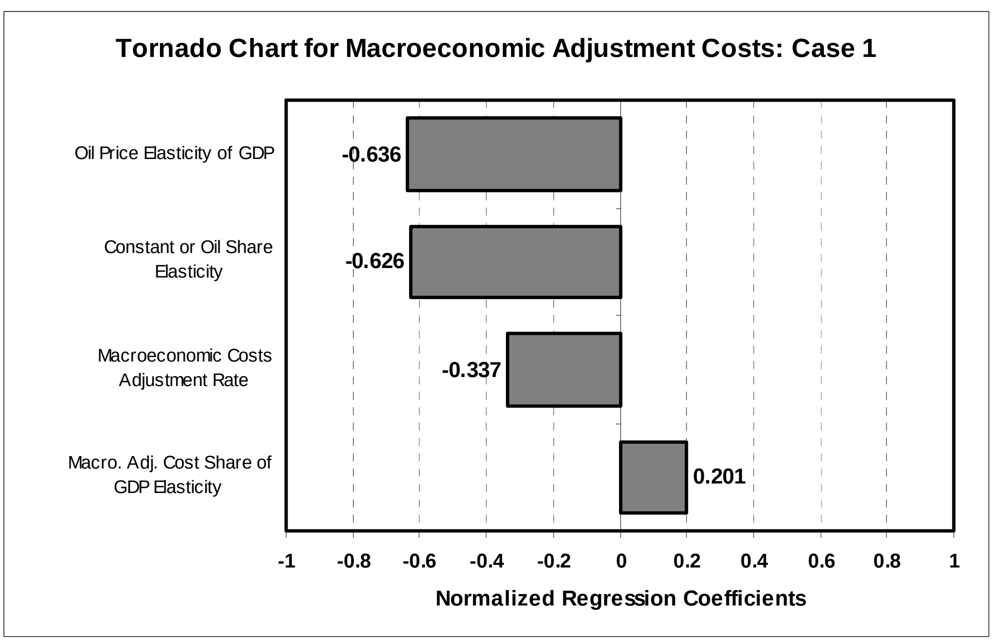

Figure 13. Sensitivity Analysis for Macroeconomic Adjustment Costs: Case 1

Total estimated losses of potential GDP are about the same magnitude as macroeconomic adjustment costs on average ($1.0 trillion) but are somewhat less variable. The 90% simulation interval runs from $0.7 to $1.5 trillion and is also skewed to the right (Figure 14).

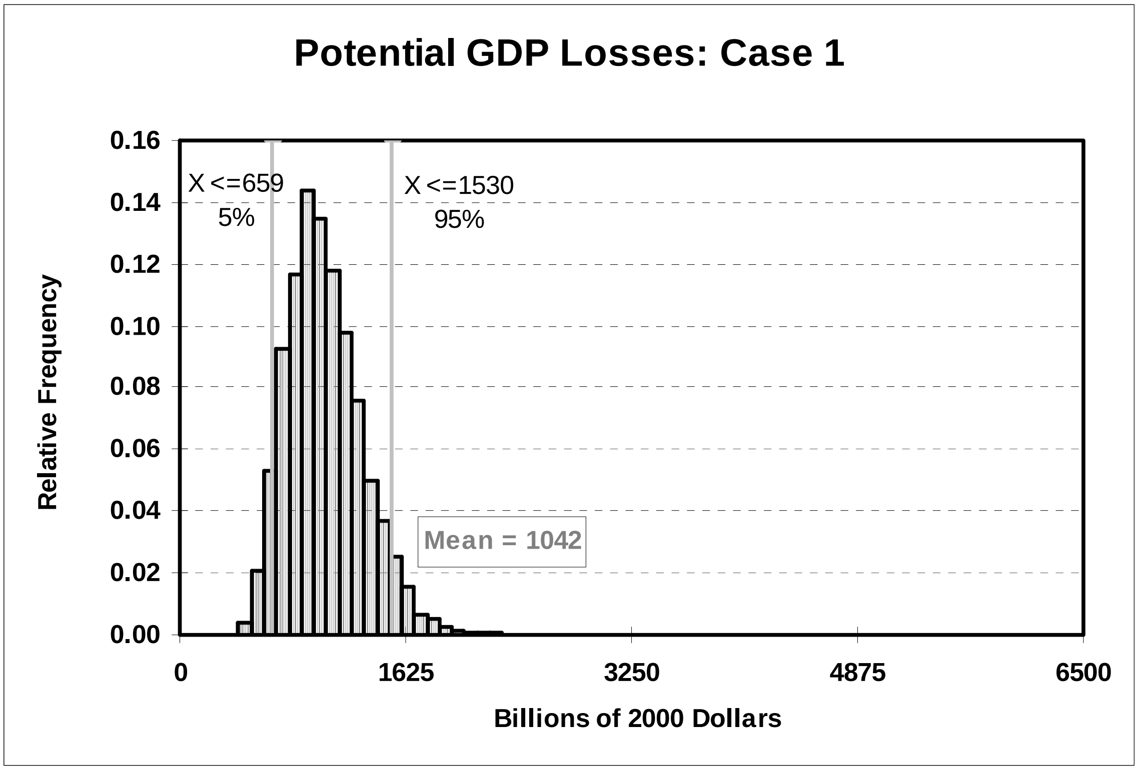

Figure 14. Frequency Distribution of Potential GDP Losses: Case 1

Potential GDP loss estimates are sensitive to the multiplier relating consumer and producer surplus losses in the oil market to economy-wide surplus losses, the assumed competitive market price of oil, the elasticities of U.S. oil demand and supply, and the rate of adjustment of the economy to oil price changes (Figure 15). Particularly interesting is the importance of adjustment rates. How fast the capital stock of energy using equipment can be turned over, how quickly oil supply can be expanded when prices rise all are important determinants of losses. An increase in the adjustment rate parameter (λ) implies an increase in the rate of adjustment. For a given short-run demand elasticity this implies a smaller long-run price elasticity. Decreasing the elasticities of demand or supply decreases the size of the surplus losses. Thus, slowing down the rates of adjustment of supply and demand appears to increase the estimated costs of oil dependence, but the real effect occurs via the increased long-run price elasticities. Because the elasticity of demand is negative and the elasticity of supply is positive, making either more elastic (increasing its absolute value) increases costs. Demand parameters are more important than supply parameters because the United States consumes roughly twice the petroleum it supplies.

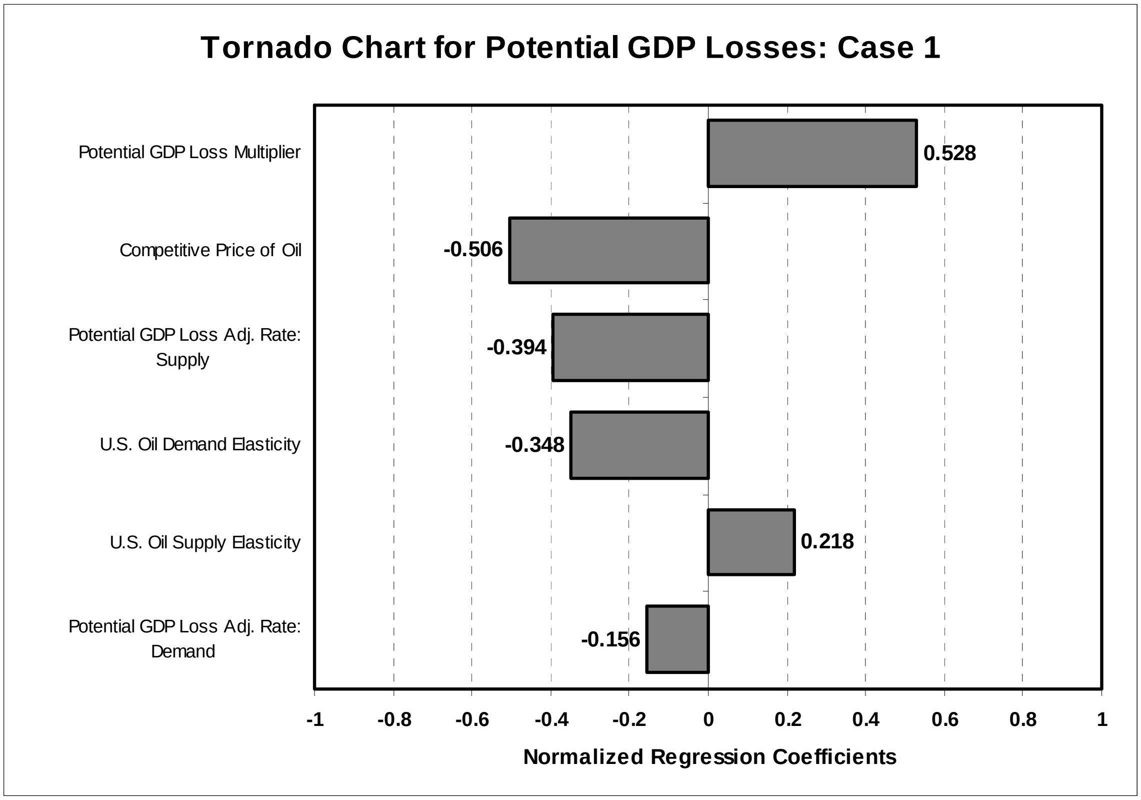

Figure 15. Sensitivity Analysis for Potential GDP Losses: Case 1

The distribution of wealth transfer costs is striking because is varies so little. With a mean value of $1.3 trillion, the 90% simulation interval is $1.1 to $1.5 trillion (Figure 16). The tornado chart shows clearly why: wealth transfer costs depend on the assumed competitive price of oil and nothing else (Figure 17). The other apparent correlations are due to the randomness of the simulations and are not significant.

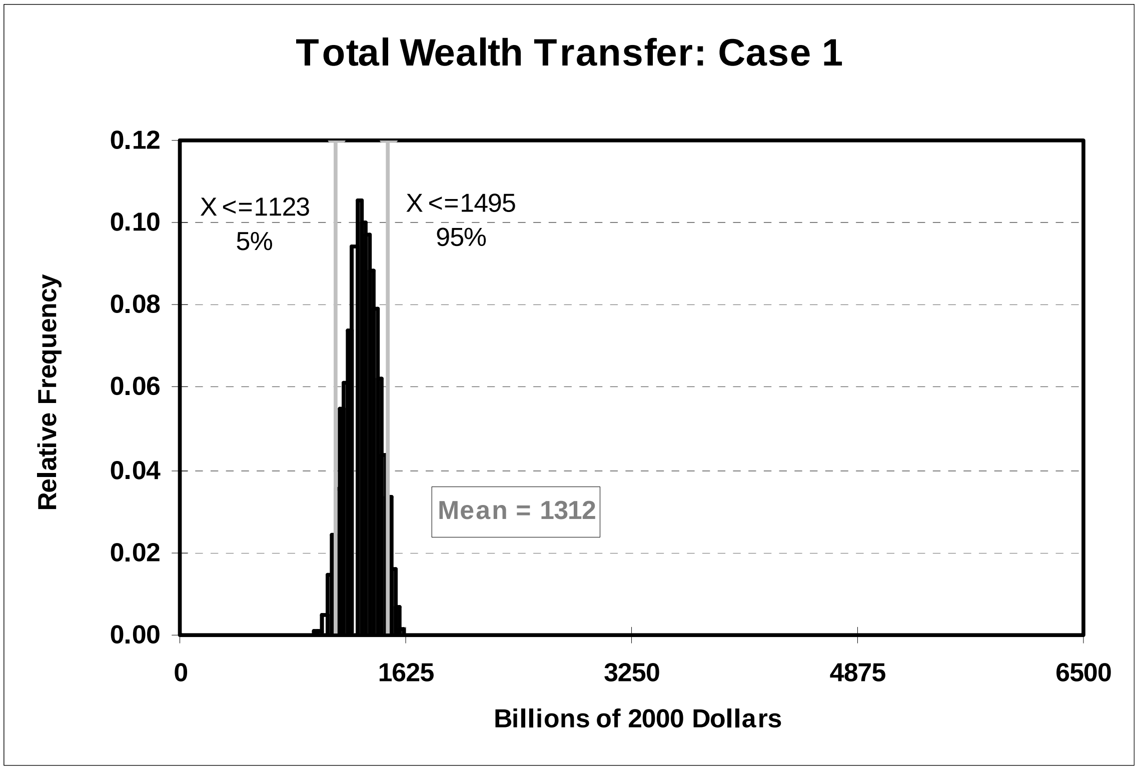

Figure 16. Frequency Distribution for Wealth Transfer Costs: Case 1

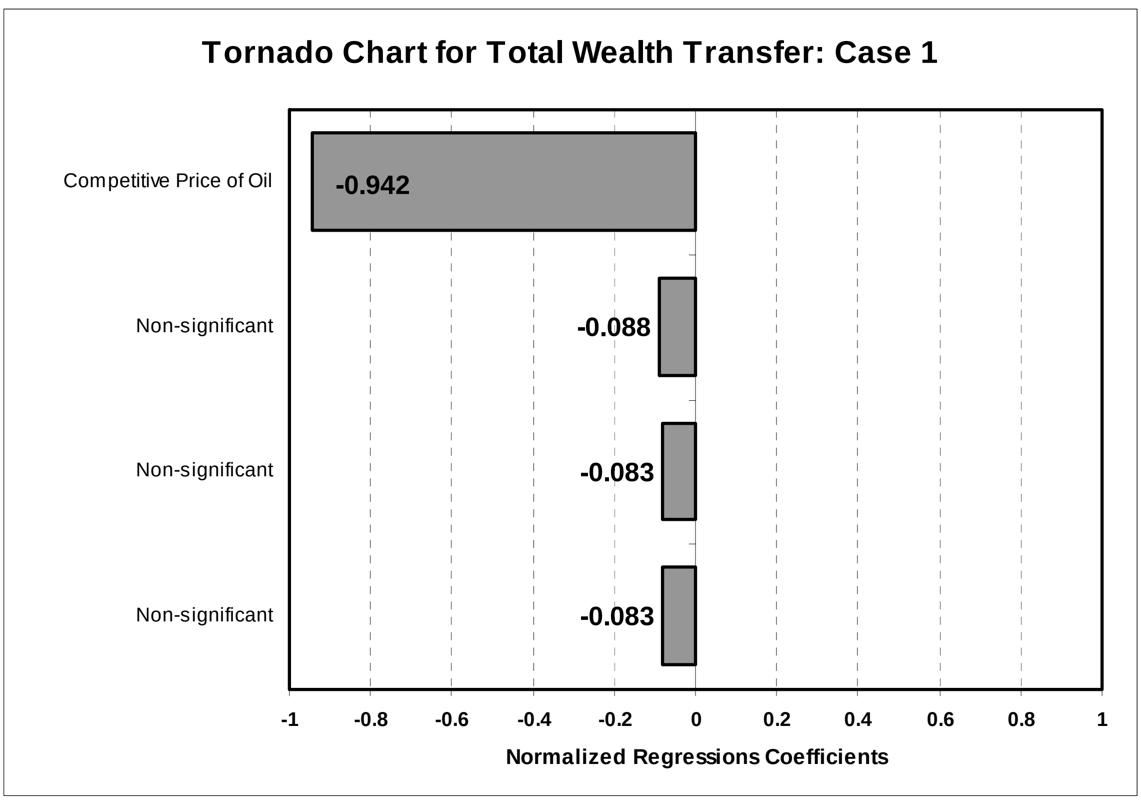

Figure 17. Sensitivity Analysis of Wealth Transfer Costs: Case 1

5.2 CASE 1A: OIL PRICE ELASTICITY OF GDP VARIES WITH OIL COST SHARE

This variant of the reference Case 1 requires the oil price elasticity of GDP to vary in proportion to the oil cost share of GDP in all simulations. The oil price elasticity parameter assumed is to apply to the year 1984, when oil expenditures as a share of GDP were near historic highs (see Figure 9). The effect of scaling the elasticity by oil expenditures relative to GDP is to reduce the estimated costs, especially in recent years. The resulting mean estimated total cost is $3.3 trillion compared with $3.7 trillion in Case 1 (Figure 18). Effectively reducing the oil price elasticity of GDP makes the competitive price of oil the most important determinant of the total costs of oil dependence in Case 1a (Figure 19). In general, other parameters determining the macroeconomic adjustment costs also become less important.

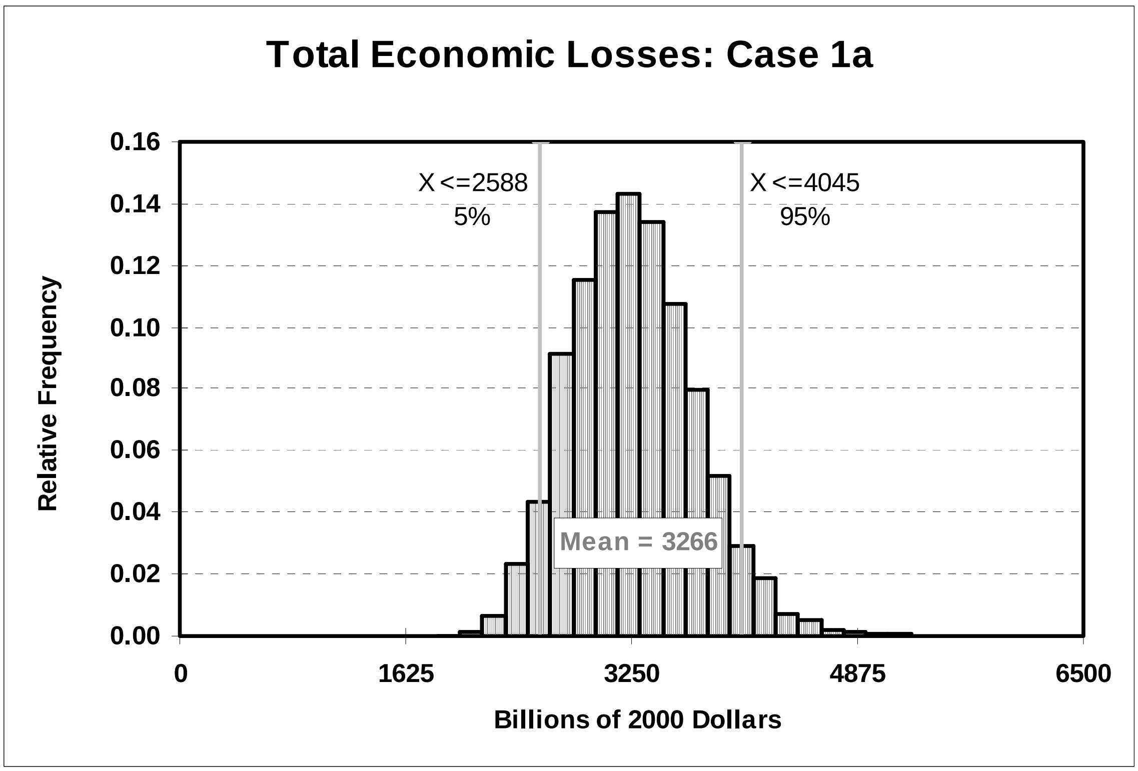

Figure 18. Frequency Distribution of Total Costs of Oil Dependence: Case 1a

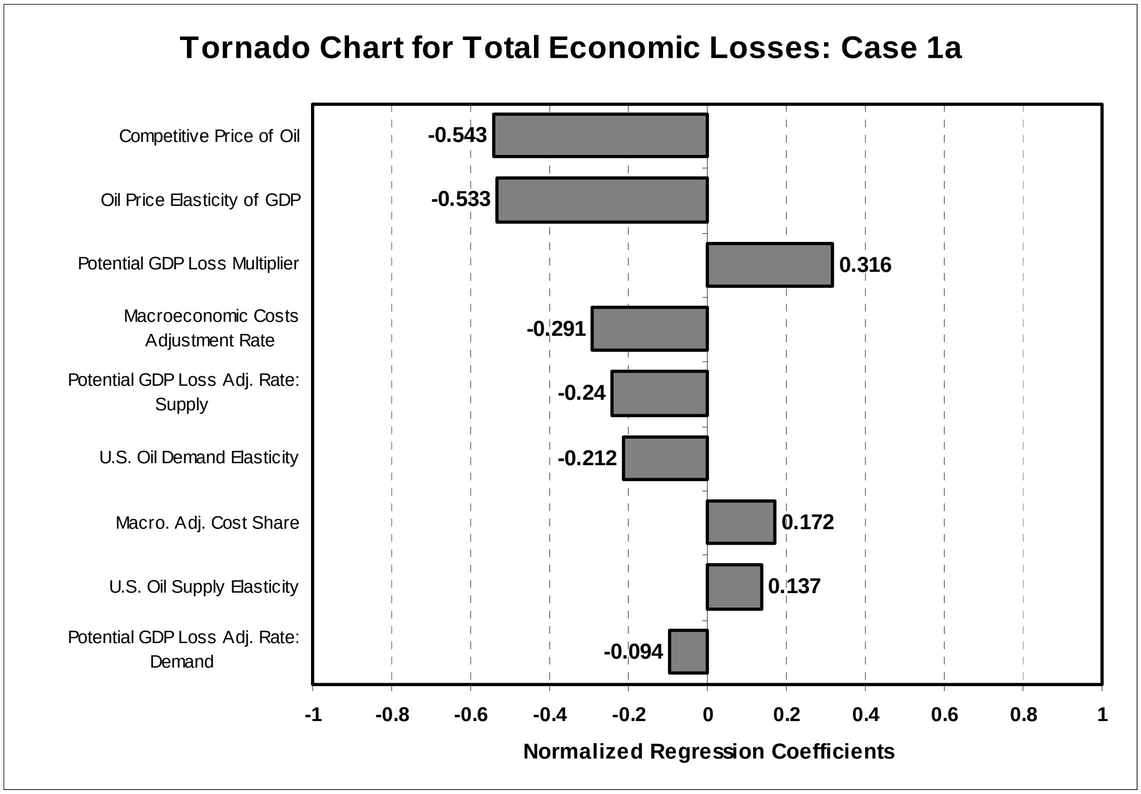

Figure 19. Sensitivity Analysis of Total Costs: Case 1a

5.3 CASE 1B: OIL PRICE ELASTICITY OF GDP CONSTANT OVER TIME

On the other hand, if the oil price elasticity of GDP is assumed to remain constant over time (it will still vary from one simulation to another), estimated total costs increase by about $600 billion in comparison to the varying elasticity Case 1a. The mean total cost estimate is $3.9 trillion, with a 90% simulation interval of $3.0 to $4.9 trillion (Figure 20). Not surprisingly, the oil price elasticity of GDP becomes the most critical parameter and all other parameters related to macroeconomic adjustment costs increase in importance (Figure 21).

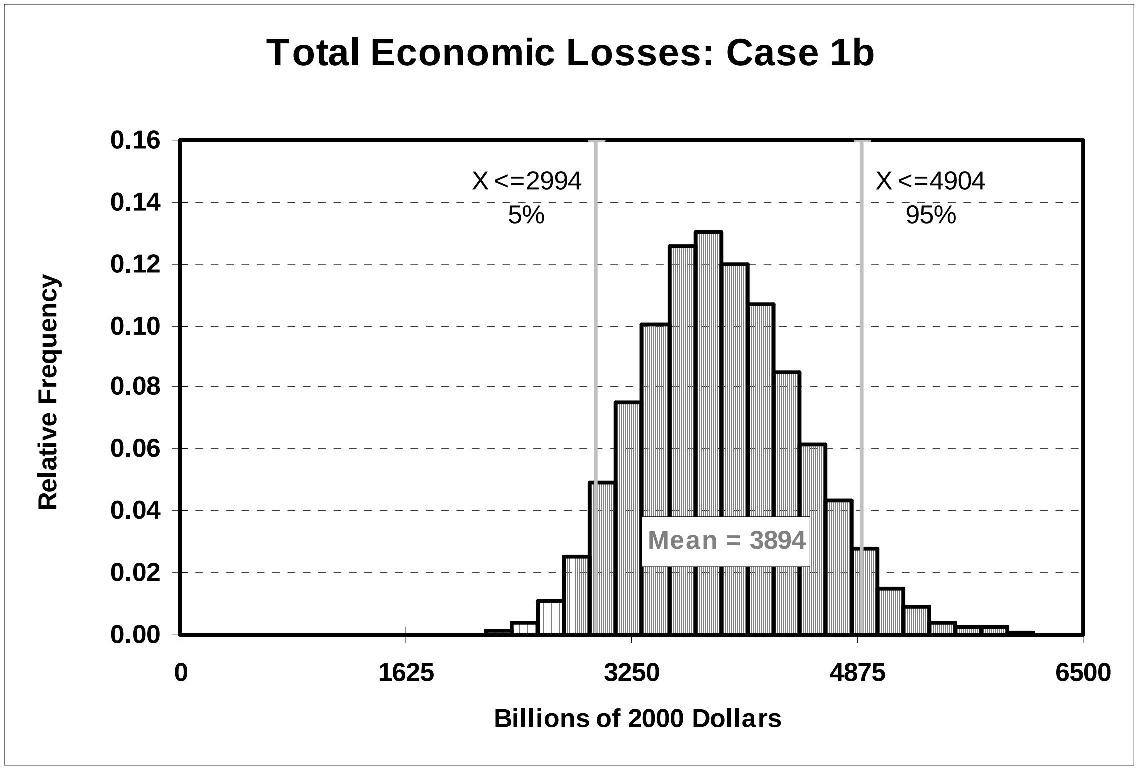

Figure 20. Frequency Distribution of Total Costs of Oil Dependence: Case 1b

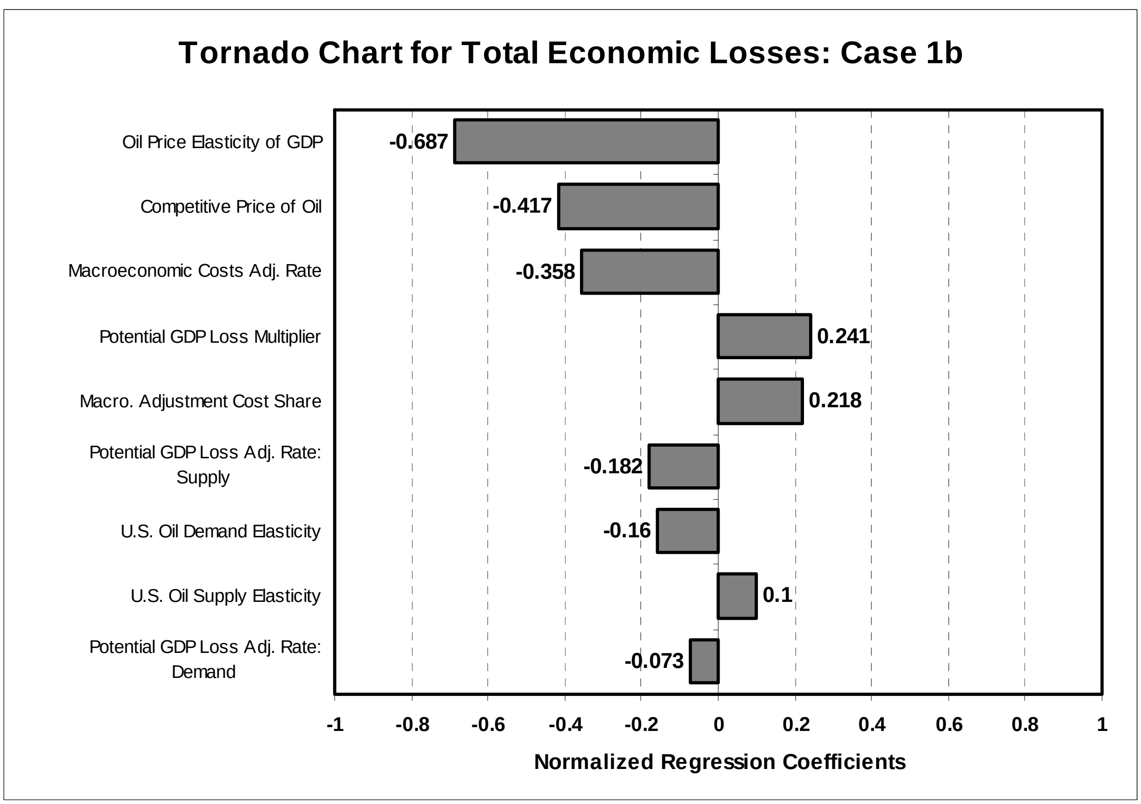

Figure 21. Sensitivity Analysis of Total Costs: Case 1b

5.4 CASE 2: STOCHASTIC COMPETITIVE PRICE PATHS WITHOUT DRIFT

Case 2 considers the possibility that a time-varying path for competitive oil prices might change the mean or variance of the estimated costs. Case 2 simulates random price paths without drift, while Case 2a include a deterministic drift parameter that is itself a random variable. As expected, random price paths have little or no effect on average cost estimates. The mean total cost estimate for Case 2 is \$3.575 trillion while that for Case 1 is \$3.580 trillion, a trivial difference (Figure 22). Even the 90% simulation ranges are very close, implying that the net effect of truly random price fluctuations on the estimated costs of oil dependence and also their variance is essentially nil. This conclusion is reinforced by the fact that the autocorrelation coefficient of the random price model does not show up in the sensitivity analysis as having a significant impact (Figure 23). Although this result may seem obvious in retrospect, it is important because it implies that comparison to a constant average competitive market price can give reliable results provided there is no trend in the mean competitive price over time.

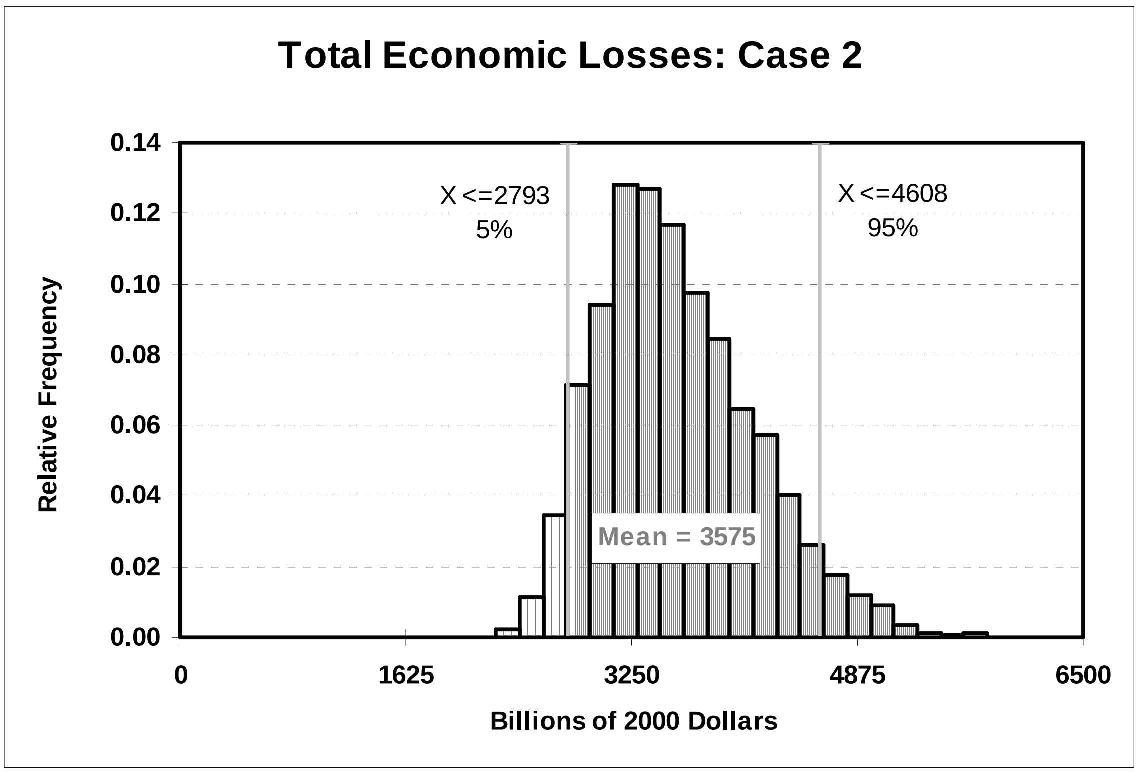

Figure 22. Frequency Distribution of Total Costs of Oil Dependence: Case 2

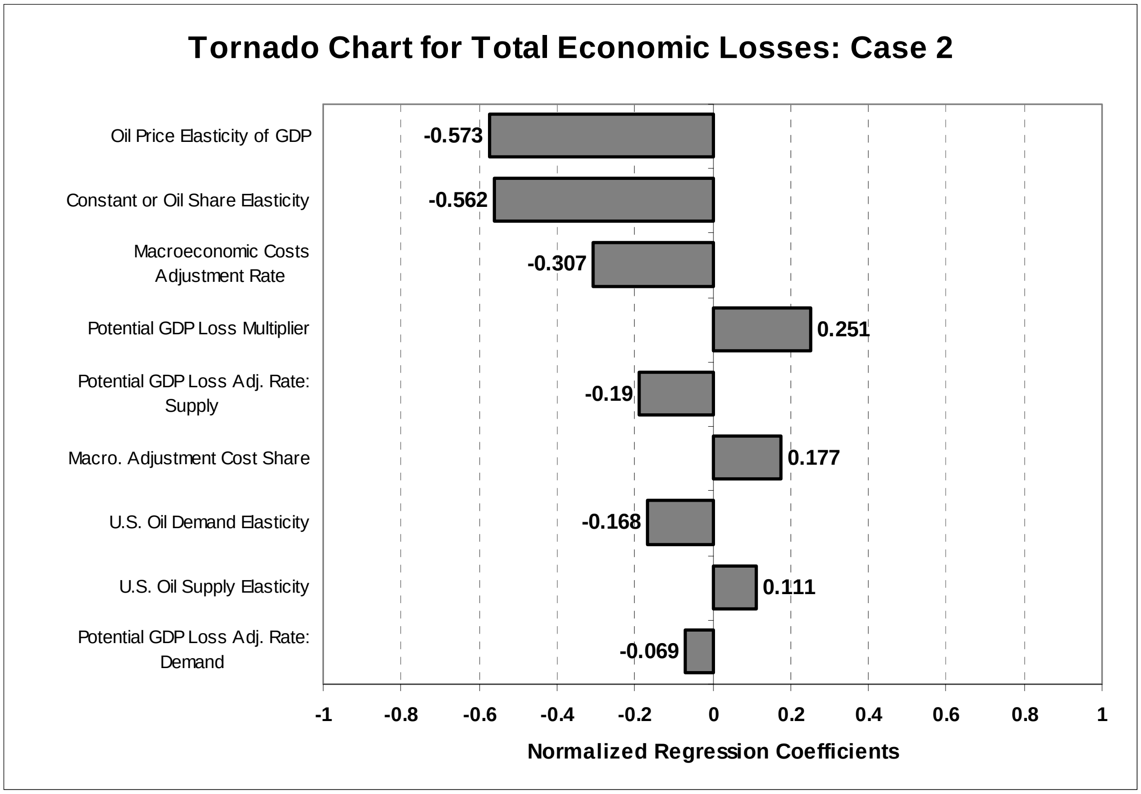

Figure 23. Sensitivity Analysis of Total Costs: Case 2

5.5 CASE 2A: STOCHASTIC COMPETITIVE PRICE PATHS WITH DETERMINISTIC DRIFT

Case 2a considers the impact of deterministic price "drift", represented by a linear trend in the mean of the random competitive price series. The competitive price still fluctuates randomly over time, but about a trending mean rather than a constant mean as in Case 2. The mean competitive price trends gradually from $13/bbl in 1973 towards a new level in 2004 somewhere between $16/bb and $10/bbl. Once again, this has little effect on the mean total cost estimate, here $3.6 trillion, essentially no different from Case 1 or Case 2 (Figure 24). The range of cost estimates is also similar but just a bit narrower. This narrower range reflects the fact that in Case 2 the mean price level varies between $10 and $16 and is the same for all years. In Case 2a the mean varies between $10 and $16 in 2004, but varies less in intervening years, always beginning at $13/bbl in 1973.

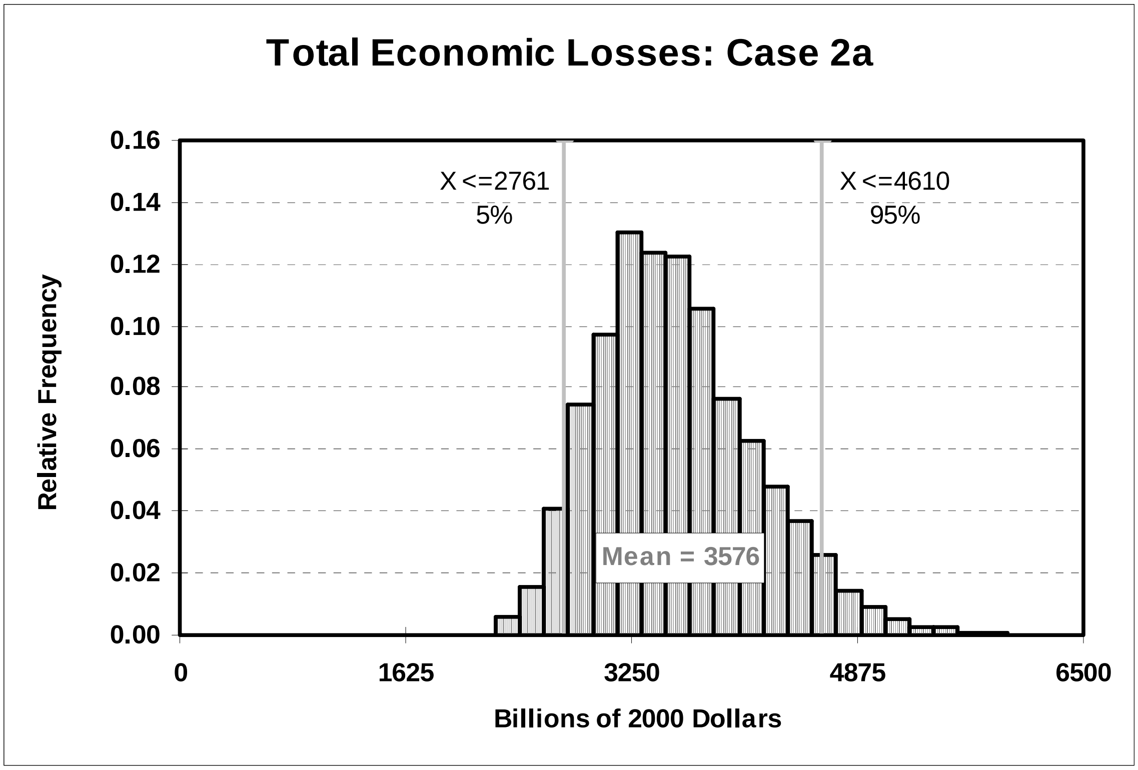

Figure 24. Frequency Distribution of Total Costs of Oil Dependence: Case 2a

The competitive price drift parameter appears in fourth place in the sensitivity analysis. One standard deviation of the drift parameter is 0.04; approximately 2.5 standard deviations is the difference between a mean price of $16 in 2004 versus $13. According to the sensitivity coefficient for drift, an increase of 2.5 standard deviations would decrease the total cost estimate by 0.5 standard deviations or about $300 billion, since one standard deviation of the total cost distribution is about $603 billion (Figure 25). This result implies that even very significant time trends in the competitive market price of oil would change the total cost estimate by less than 10%. The robustness of the estimates to both trends and random fluctuations in the hypothetical competitive market price of oil suggests that the general magnitude of the total cost estimates is reliable.

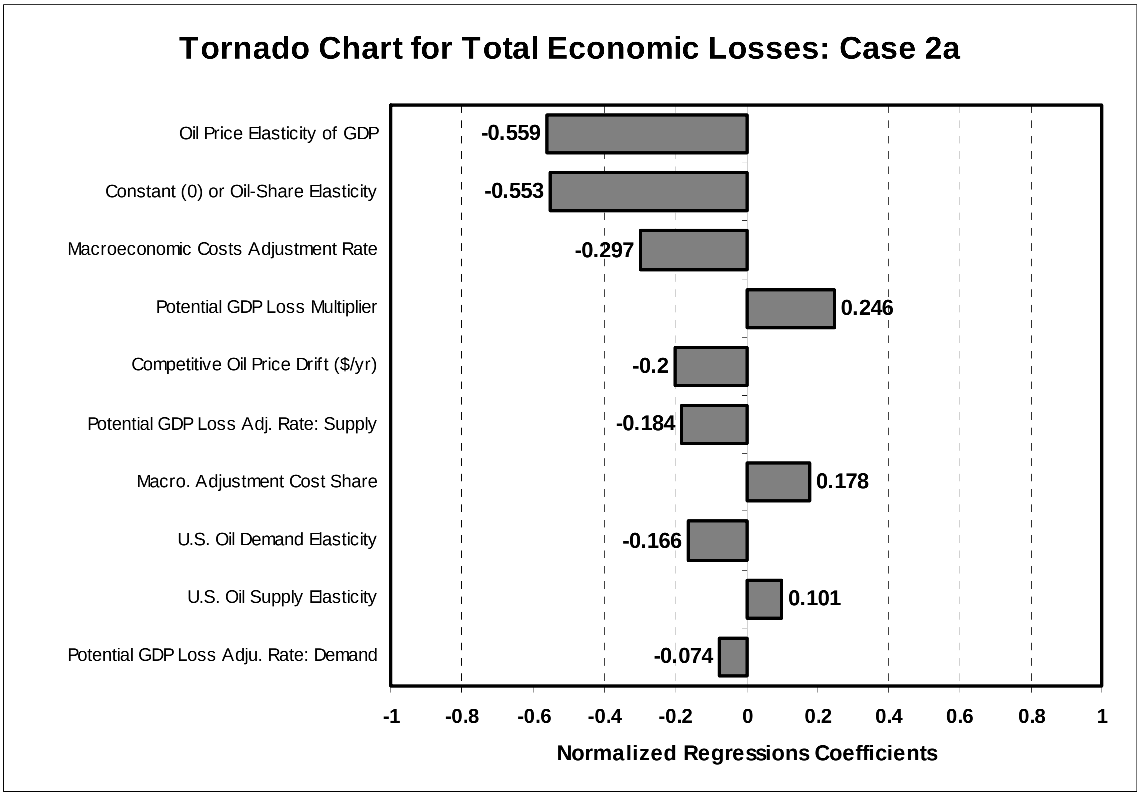

Figure 25. Sensitivity Analysis of Total Costs: Case 2a

Most of the influence of the competitive price of oil on the total costs of oil dependence comes via its impact on the transfer of wealth, for which it is the only important assumption (normalized regression coefficient of -0.9 and no other parameter has a statistically significant coefficient).

5.6 THE IMPACT OF CONTINUED HIGH OIL PRICES IN 2005

Oil prices surged to over $50/bbl in 2004. The spot market price of Brent crude oil increased from $31/bbl in January and February to $50.50/bbl during the third week of October. Prices moderated somewhat in November, remaining within the range of $40-45/bbl for most of the month. As a result, the average refiner acquisition price of crude oil in 2004 was approximately $37.50/bbl. What the price of oil will be for 2005 is, of course, highly uncertain. The Energy Information Administration's February 2005 Short Term Energy Outlook foresees high oil prices throughout 2005.

> "The projected average West Texas Intermediate (WTI) crude oil price for the first quarter of 2005 is about $46.70 per barrel, approximately $11 per barrel higher than in the first quarter of 2004 and $3 per barrel above the first quarter projection in the previous Outlook. EIA projects that WTI prices are likely to remain in the low- to mid-$40's per barrel range throughout 2005-2006. However, oil prices are likely to be sensitive to any incremental supply tightness that appears during periods of peak demand worldwide." (US DOE/EIA, 2005, 2/9)

WTI crude trades at a premium in comparison to the average barrel of imported oil. EIA projects that the average cost of crude to U.S. refiners will be $39.13 (nominal dollars) per barrel in 2005, falling slightly to $37/bbl in 2006 (US DOE/EIA, 2005, table HL1).

The following projections assume that the macroeconomic adjustment cost oil price elasticity of GDP is proportional to oil costs as a share of GDP. If oil prices in 2005 were to fall back to the 2004 average of $39.13/bbl, ($35.51 in constant 2000 dollars) the costs to the U.S. economy of oil dependence would increase in 2005 to approximately $175 billion (Figure 26). The increase in costs over 2004 despite a modest increase in price is a reflection of the lag in the impact of oil prices on the economy. If U.S. GDP increases to $11 trillion in 2005, oil dependence costs of $175 billion would amount to 1.6% of GDP, not the highest level on record but a very significant negative economic impact. The above estimates assume that the sensitivity of the economy to oil price shocks has decreased over time in proportion to the expenditures on oil as a share of GDP. If one assumes that the oil price elasticity of GDP has remained constant at -0.055, the costs of oil dependence in 2005 would be approximately $220 billion assuming an average price of imported oil of $35.50/bbl (constant 2000 dollars).

However, if the price of imported oil were to rise to just over $50/bbl ($50.15/bbl or $45.50 in constant 2000 dollars) the costs of oil dependence in 2005 will reach $250 billion (Figure 27). In constant dollars this approaches the peak year for estimated economic impact, 1981, but is just over 2% of projected GDP for 2005.

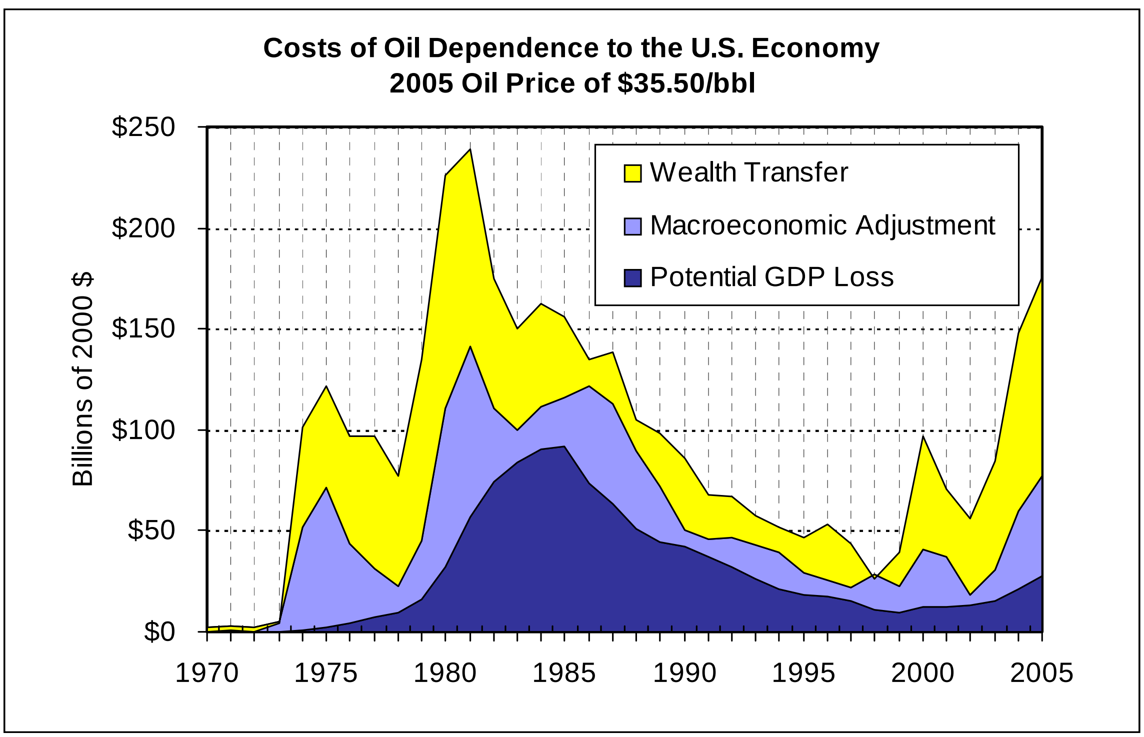

Figure 26. Costs of Oil Dependence to the U.S. Economy 2005 Losses Projected for $37.50/bbl Oil

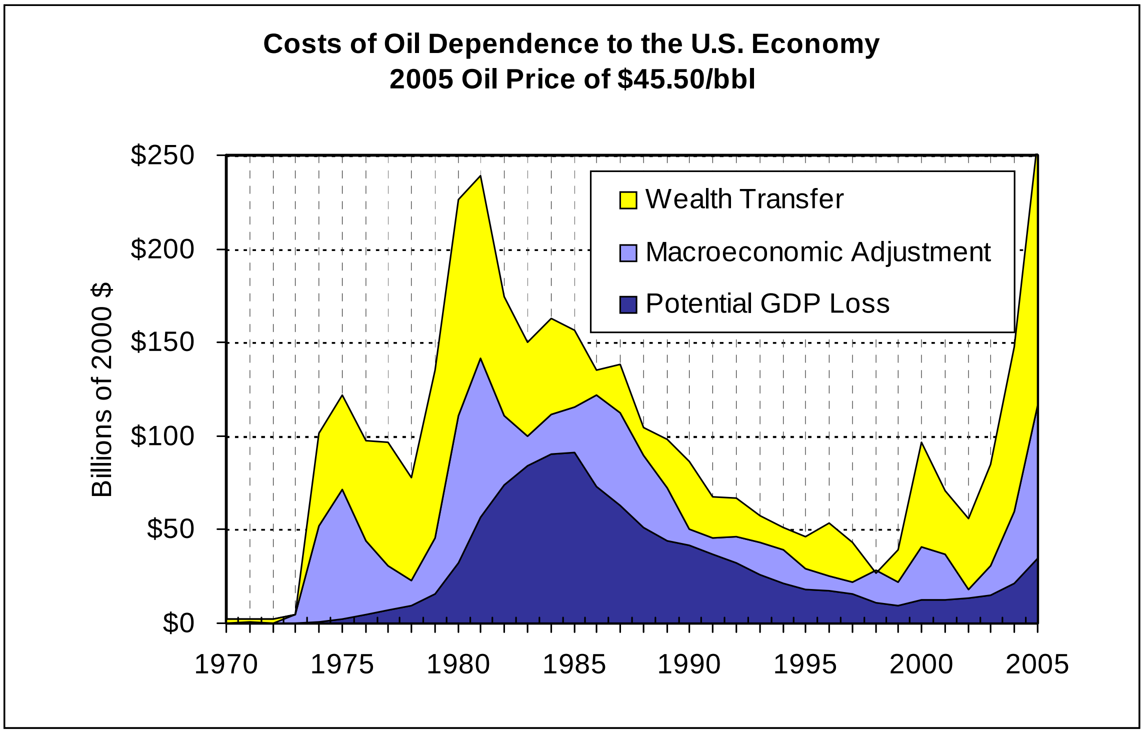

Figure 27. Costs of Oil Dependence to the U.S. Economy
2005 Losses Projected for $47.50/bbl Oil

6. CONCLUSIONS

6.1 COSTS OF OIL DEPENDENCE AND TRENDS

The costs to the U.S. economy of oil dependence have been large. Our 2000 study estimated the sum of costs from 1970-2000 at $3.5 trillion in constant 2000 dollars, or $7.3 trillion when adjusted to present value (Greene and Tishchishyna, 2001). This study's reference case estimated total costs at $3.6 trillion through 2004 in constant 2000 dollars, or $8 trillion adjusted to present value. The new method of estimating potential GDP costs and updated parameter values used in this study produces somewhat lower estimates than the method used in our 2000 study, so the numbers are not precisely comparable.

Relative to the size of the economy, oil dependence is perhaps half as important as it was in 1980. In constant dollars, however, the costs to the U.S. are roughly the same. After more than a decade of relatively low and decreasing costs of oil dependence, constant dollar impacts on the U.S. economy have returned to levels not seen since the early 1980s. If oil prices continue through 2005 at current levels oil dependence will cost the U.S. economy over $200 billion in 2005. In constant dollars, this is close to the costs suffered in 1980 and 1981. As a percent of GDP, however, the 2005 impact will be only half as large as the 1980-81 impacts because GDP has doubled in the intervening years.

A thorough sensitivity analysis of the oil dependence cost estimates has been carried out by means of Monte Carlo simulation. The analysis shows that while the choices made for several key parameters have a significant impact, the costs of oil dependence since 1970 almost certainly exceed $2.7 trillion constant 2000 dollars by any reasonable choice of parameters, and could be as large as $4.7 trillion. This is a considerably narrower range of uncertainty than that reported in our 2000 study, $1.7 to $7.1 trillion, and reflects the superiority of Monte Carlo based sensitivity analysis versus "worst case/best case" scenario analysis.

This analysis also confirms that the three components of oil dependence costs (wealth transfer, potential GDP loss, and macroeconomic adjustment costs) are approximately equal in size. Thus, focusing on the costs of oil price shocks alone and ignoring wealth transfer and the persisting effects of high oil prices on potential GDP losses would underestimate the true costs of oil dependence by about a factor of 3.

6.2 LIMITATIONS, UNCERTAINTIES, AREAS FOR FUTURE RESEARCH

This analysis has several important limitations. First, it is based on a simulation using elasticities to estimate macroeconomic costs and demand and supply curves plus an indirect impact multiplier to estimate losses of potential GDP. This approach has the advantages of simplicity and of allowing consensus parameters from the literature to be used, but it has the disadvantage of not explicitly representing the much greater number of market interactions incorporated in integrated macroeconomic models. Second, no one will ever know what path oil prices would have followed had there been no OPEC. This has been partly addressed through Monte Carlo simulations but important issues remain. For example, had there been no OPEC and market prices had remained low throughout the 1980s, would there have been the same important technological innovations in oil exploration and development (e.g., 3-D seismic imaging and intelligent, directional drilling)? Would faster rates of production at lower prices have led to a trend of rising oil prices over time or instead, without OPEC, would oil have followed the path of so many mineral resources whose prices have declined over time?

Many of the limitations of this analysis have to do with uncertainty about the correct values of key parameters. Examples noted above include (1) whether the oil price elasticity of GDP has been constant over time or varies with the importance of oil to the economy, (2) what is the correct division of GDP losses between macroeconomic and potential GDP losses, (3) what is the correct multiplier to translate oil market surplus losses into surplus losses throughout the economy, and (4) what are the correct values for supply and demand elasticities and adjustment rates? These issues can be only partially addressed by means of sensitivity analysis. Further, detailed research on the impacts of oil prices on the economy could help refine these assumptions.

Finally, the estimates presented here reflect only the direct economic costs of oil dependence. Military, strategic and political costs as well as indirect costs (such as the SPR) have not been estimated here and they are undoubtedly very large indeed.

Despite these caveats, this analysis has confirmed that oil dependence was and now is once again an enormous economic problem for the United States.

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