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Costs of Oil Dependence: A 2000 Update

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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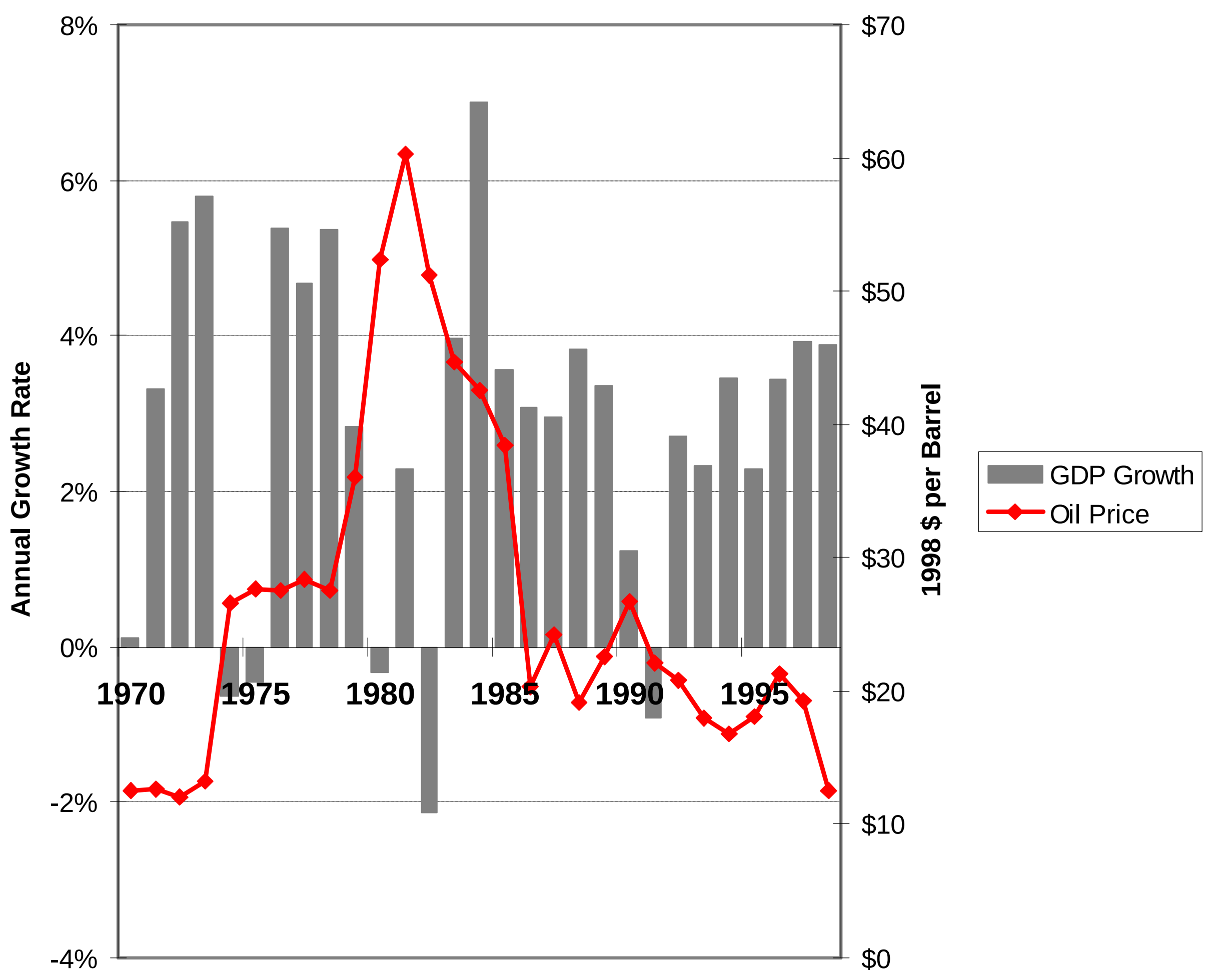
ABSTRACT

Oil dependence remains a potentially serious economic and strategic problem for the United States. This report updates previous estimates of the costs of oil dependence to the U.S. economy and introduces several methodological enhancements. Estimates of the costs to the U.S. economy of the oil market upheavals of the last 30 years are in the vicinity of $7 trillion, present value 1998 dollars, about as large as the sum total of payments on the national debt over the same period. Simply adding up historical costs in 1998 dollars without converting to present value results in a Base Case cost estimate of $3.4 trillion. Sensitivity analysis indicates that cost estimates are sensitive to key parameters. A lower bound estimate of $1.7 trillion and an upper bound of $7.1 trillion (not present value) indicate that the costs of oil dependence have been large under almost any plausible set of assumptions. These cost estimates do not include military, strategic or political costs associated with U.S. and world dependence on oil imports.

1. INTRODUCTION

Oil dependence remains a potentially serious economic and strategic problem for the United States. Estimates of the costs to the U.S. economy of the oil market upheavals of the last 30 years are in the vicinity of $7 trillion, present value 1998 dollars, about as large as the sum total of payments on the national debt over the same period. Each of the three major oil price spikes of the last thirty years (1973-74, 1979-80, 1990-91) was followed by an economic recession in the United States (Figure 1). When oil price fell to $10 per barrel in the winter of 1998-99, it seemed reasonable to ask whether oil dependence was still an important issue. The American public continued to believe that it was. A 1998 poll found that over 80% of respondents considered oil dependence a very, or somewhat significant threat to U.S. jobs and to our standard of living (Sustainable Energy Coalition, 1998). Recent events have confirmed the public's belief. If oil prices continue through 2000 in the neighborhood of $25 per barrel, U.S. GDP will be reduced by about 1%.

Figure 1. OIl Price and Economic Growth, 1970-98



Past estimates of the costs of oil market disruptions to the U.S. economy have ranged in the trillions of dollars. In this paper, past cost estimates are updated and extended (e.g., Greene and Leiby, 1993) based on the best available evidence and most current data, and a systematic set of sensitivity analyses to bound the range of reasonable estimates is carried out. An important error in an earlier analysis (Greene and Leiby, 1993) is corrected and a more rigorous method has been used to calculate an important component of the impact of oil prices on GDP. Yet, once again it is clear that the exercise of market power in world oil markets has been very costly to the U.S. economy. Our range of plausible estimates for total U.S. economic costs from 1970–99 is from $1.7 trillion to $7.1 trillion undiscounted 1998 dollars, and from $3.8 to $13.7 trillion present value 1998 dollars.

The terms energy security and oil dependence have been used frequently and, more often than not, loosely. Oil dependence is often equated with the quantity of U.S. oil supply that must be imported. Reliance on imported oil is a component of the oil dependence problem, but "To import or not to import?" is not the question. Even when OPEC production cuts make oil prices jump, the U.S. economy is better off paying the higher prices for imports rather than trying to rely solely on domestic sources of supply (GAO, 1996).

Oil dependence is the product of (1) a non-competitive world oil market strongly influenced by the OPEC cartel, (2) high levels of U.S. oil imports, (3) the importance of oil to the U.S. economy (especially the transportation sector), and (4) the absence of economical and readily available substitutes. The exercise of market power and extraction of monopoly rents by the OPEC (or OPEC+) cartel would not be possible in a competitive market. Unfortunately, there is no global institution capable of enforcing competitive behavior in world oil markets. Oil dependence is a cost to the U.S. economy because it is the direct result of a market failure and because there are things the United States, as a nation, can do about it. Developing advanced technologies to increase the efficiency of energy use in transportation, lower the costs of alternative energy sources, and improve the technology of oil exploration and recovery will help counteract market power in world oil markets and significantly reduce the costs of oil dependence (Schock et al., 1999).

More than a quarter century has passed since the oil market upheaval of 1973-74 shifted the balance of economic power in world oil markets from the industrialized consuming economies to the oil producing states (Yergin, 1992). Since 1974, there have been three significant price increases associated with the Iran-Iraq war in 1979, the Persian Gulf War in 1990, and the collaboration between OPEC, Mexico and Norway in 1999. Sandwiched between came the oil price collapse of 1986. In 1998 real oil prices dropped to levels not seen since 1970, only to return to $20 and then climb to $30 per barrel after OPEC states agreed to reduce output. This most recent round of production cuts proved beyond any reasonable doubt that OPEC (assisted by Mexico, Norway, Russia and Oman) still wields considerable market power.

U.S. net imports of oil reached their highest recorded level in 1998, 51.6% of U.S. petroleum supply. With higher oil prices in 1999, import dependence decreased slightly to 49.6% of total U.S. oil requirements. With net imports averaging 9.6 mmbd, and the average price of imported oil at $17.23 per barrel, the economy spent $60 billion on imported oil in 1999. If prices average

$30 per barrel in 2000 and imports decrease to 9.0 mmbd, the United States will spend almost $100 billion on imported oil. Assuming a hypothetical competitive oil price of $10 per barrel, $66 billion of that bill will be a transfer of U.S. wealth to foreign oil producers due to the monopolistic pricing policies of OPEC.

While the importance of oil to the U.S. economy has recently been at a thirty year low, its economic significance has increased with increasing prices. In 1998, the United States consumed 6.9 billion barrels of oil at an average price of $12.52 per barrel, for a total expenditure of $86.4 billion. The importance of oil to the economy (measured by expenditures on oil as a percent of the $8.5 trillion GDP) stood at 1.0%, considerably down from the 4-6% shares of the early 1980s, but not much below its 2% share when the first OPEC oil price shock hit in fall of 1973. Because demand for oil is inelastic, its cost share increases with the price of oil. In 1999, oil price averaged $17.46 per barrel. At the same time, oil consumption rose to 7.1 billion barrels, and total expenditures $123.6 billion. With GDP increasing by about 7%, the oil cost share grew to 1.4%. If oil prices remain in the vicinity of $30 through 2000, and oil consumption is 7 billion barrels, the oil cost share of GDP will increase to about 2.2%.

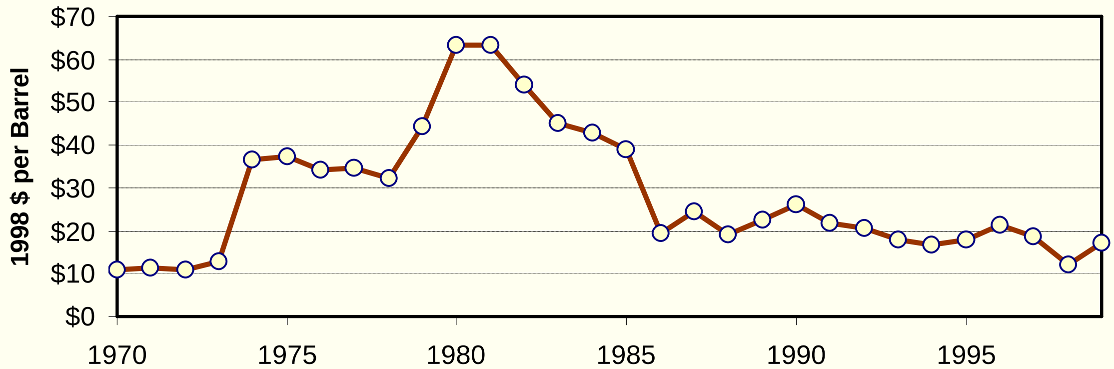
The utility, residential and commercial sectors of the U.S. economy have reduced their oil use dramatically since the 1970s. Industrial oil use has held nearly constant, but transportation sector oil use increased 40% from 1973 to 1998. So while the cost of oil as a share of GDP has been reduced, its use has become even more concentrated in the sector that remains 95% dependent on oil and has historically demonstrated the least ability to respond to price shocks by switching to alternative fuels.

The oil price collapse of 1986, followed by more than a decade of lower oil prices, convinced many that OPEC's days as a dominant force in world oil markets were over (Figure 2). Even the brief price spike in 1990-91 as a result of the Persian Gulf War was seen as an aberration. As recently as last winter, refiners were paying $10 per barrel for imported oil and supplies were abundant. Consensus oil price forecasts foresaw prices within the range of $15 to $26 per barrel by 2010, and remaining roughly in that range through 2020 (U.S. DOE/EIA, 1999, table C1).

But as 1999 unfolded, the consensus view of an ineffectual OPEC and a future of abundant, cheap oil has been overturned by a steady rise of oil prices to $24 per barrel in January 2000. Not only was the more than doubling of oil prices largely unexpected, but it was brought about by effective action by a revitalized cartel, comprised of the 11 OPEC members plus Mexico and Norway. On March 22, 1998, the new coalition announced production cuts of 1.6 million barrels per day (mbpd) (Salpukas, 1999). This action was unsuccessful in raising energy prices for a sustained period, as sagging Asian economies held down the demand for oil. In 1999, Asian economies began to recover and the new cartel agreed on additional production cuts totaling about 5.3 mbpd, thereby engineering a doubling of world oil prices. As a reporter for the New York Times observed:

> "But now, again, a single coalition accounts for more than half of world oil production, a share that OPEC itself had not held since the 1970's. And this cartel could be around for a while." (Salpukas, 1999, p. 4)

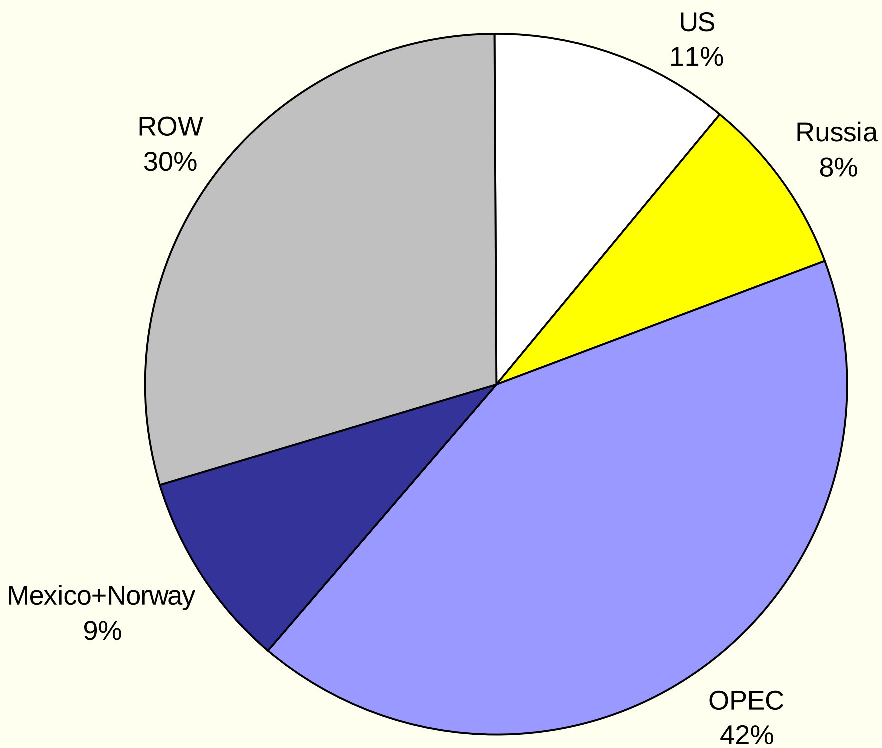
Figure 2. U.S. Refiners' Acquisition Cost for Imported Oil, 1970 - 1999



Or it could reformulate itself yet again, possibly adding fossil fuel rich states of the former Soviet Union (Figure 3). In 1999, the world rediscovered what Daniel Yergin so thoroughly documented in *The Prize* in 1991. When the opportunity exists to obtain vast wealth by manipulation of the world oil market, eventually a way will be found to do it.

For more than a quarter century, U.S. policy makers have struggled over what to do about the high cost of oil dependence, and economists have debated what if any role the government can or should play in solving the problem. Key sources of OPEC's market power are their enormous share of the world's conventional oil resources and the lack of ready and efficient substitutes for oil. The cartel's market power can be undermined by: (1) improving and lowering the costs of alternative fuels and alternative fuel-using engines, (2) increasing the energy efficiency of petroleum-using equipment, (3) developing less costly technologies for converting unconventional energy sources to petroleum fuels, and (4) lowering the costs and increasing the recovery of conventional petroleum for the world's non-OPEC producers. Recent analyses have shown how dramatically such technological changes could affect the future costs of oil dependence (Greene, 1997; Greene et al., 1998; Schock et al., 1999)

Figure 3. Shares of World Oil Production, 1998



2. COST COMPONENTS

When monopoly[1] power is used to raise prices above competitive market levels, oil consuming economies incur three categories of costs: (1) the economy's ability to produce is reduced because a key factor of production is more expensive, (2) sudden changes in oil prices increase unemployment, further reducing economic output, and (3) some of the wealth of oil consuming states is appropriated by foreign oil producers. In this report, revised and updated estimates will be presented for each of these three components (Greene and Leiby, 1993). Military, political, and environmental costs of oil dependence (which are also substantial) are not estimated.

2.1 LOSS OF POTENTIAL GDP

When the price of oil is raised by the use of monopoly power, the increased price of oil signals the economy that a fundamental resource has suddenly become more scarce. As a result, the economy is able to produce somewhat less with the same endowment of capital, labor, materials, and other energy resources. This shrinkage is called the *loss of potential GDP*, to emphasize that even if all resources are fully employed in their best uses, the potential to produce is reduced because (economically) oil is more scarce. The loss of potential GDP is permanent, in the sense that it persists as long as oil prices remain elevated.

If oil prices rise suddenly, economic dislocations cause further losses of GDP. Delays in adjusting prices, wages and interest rates throughout the economy to the sudden price change result in less than full employment of available resources. As a result, economic output falls below its full potential. Since such *macroeconomic adjustment costs* result from the economy's inability to respond quickly, they are temporary, and are believed to dissipate within three to five years.

2.2 MACROECONOMIC ADJUSTMENT COSTS

Macroeconomic adjustment costs are the most complex of the three cost components because they depend not only on the price shock itself, but on policy responses (e.g., contraction or expansion of the money supply) and on expectations about the duration of the price increase (Lee et al., 1995). Until the 1990s there was little economic research identifying and measuring the mechanisms by which oil price shocks caused macroeconomic adjustment losses. A detailed

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[1] Some argue that because OPEC states do not control 100% of the oil market, it is incorrect to use the term monopoly power. This is too strict an interpretation of the term and misses the point. It would be difficult to find many monopolies in the history of the world that controlled an absolute 100% of any market. The more correct terminology for OPEC is a von Stackelberg monopolistic cartel, as will be explained below. The important point is that the cartel, when it is able to act in concert, has had considerable market power, which has given it the ability to raise prices well above competitive market levels, to its benefit and to the detriment of consumers, like the United States.

statistical analysis of the impacts of oil price shocks on job creation and destruction in the U.S. manufacturing sector (Davis and Haltiwanger, 1997) found that both oil price shocks and monetary shocks caused much greater job destruction that job creation, but that oil price shocks were about twice as important as monetary shocks. Moreover, the study found that the most energy intensive sectors suffered more than twice the employment losses as the least energy intensive sectors. This analysis confirmed Lougani's (1986) early finding that oil price shocks caused a need for labor reallocation that led to a temporary increase in unemployment, persisting for perhaps 4 years.

2.3 TRANSFER OF WEALTH

The third component of oil dependence costs is a *transfer of wealth* from oil consuming to oil producing states. When the OPEC cartel drives up prices by restricting output, it creates monopoly rents for its members without the need for them to expend real resources to produce anything. By disciplined production cuts, the cartel is able to appropriate wealth from the rest of the world. Some of the increased import bill of oil consuming economies goes to non-OPEC oil producers who may have to expend real resources to expand their oil production. Even this increase in oil import costs counts as a loss of wealth to oil consuming economies. Sometimes this is also referred to as a worsening of the terms of trade, reflecting the fact that consuming nations must exchange more real resources for the same quantity of oil due to the exercise of monopoly power by the oil producers' cartel. The transfer of wealth is not a loss of global economic output since wealth lost by consuming nations is retained by producing nations. It is, however, a real economic loss to the United States as a consuming nation.

3. MEASURING THE COSTS

The use of market power to raise oil prices causes economic losses for the world as a whole and transfers wealth from consuming to producing nations.[2] Few economists would argue with this assertion. But compared to what? Estimating the historical costs of oil dependence requires specifying what world oil markets would have been like if oil producers had not formed OPEC and exercised monopoly power. In reality, OPEC did influence world oil markets and price shocks OPEC initiated or capitalized on were followed by recessions in the United States. Compared to what alternative should the costs to the U.S. economy of these events be measured? Measuring the costs of oil dependence is therefore necessarily an exercise in counterfactual analysis. The alternative assumed here is a competitive world oil market, with stable oil prices such as prevailed prior to the first oil price shock in 1973.

3.1 TRANSFER OF WEALTH

The transfer of wealth is the most directly measurable component of the costs of U.S. oil dependence. A simplified representation of the U.S. petroleum market is shown in Figure 4. U.S. oil supply is insufficient to supply U.S. demand at the initial competitive world oil price, P_o. U.S. supply is ${}^{S}Q_o$, demand is ${}^{D}Q_o$, so $({}^{D}Q_o - {}^{S}Q_o)$ is imported. When the cartel raises the world oil price to P_1, U.S. imports decrease to $({}^{D}Q_1 - {}^{S}Q_1)$. The transfer of wealth from the U.S. economy is exactly equal to the shaded rectangle in Figure 5. It is the product of total U.S. imports and the difference between the actual price of oil and the price that would prevail in a competitive world oil market.

For years between 1973 and today, the competitive price is hypothetical and cannot be directly observed, so it is impossible to determine its value with certainty. We use three different indicators to suggest what a reasonable competitive market oil price might have been: (1) the price of oil before the first OPEC-created oil price shock in 1973; (2) the lowest price of oil on record since 1973, and (3) the range of estimates from modeling analyses which attempted to estimate a competitive market price for oil. Fortunately, all three estimates point to the vicinity of $10 per barrel in 1992 $, or $11.27 in 1998 $.

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[2] Some object to counting the transfer of wealth as an economic cost to the United States. They point out that a wealth transfer is not a true loss of welfare to the world, since only the ownership of wealth changes and wealth is not destroyed. This is true, but does not change the fact that it is a true loss of wealth to the United States. If estimating the costs of oil dependence to the world as a whole, one would not count the transfer of wealth. Others point out that the United States is a well-to-do nation and that a transfer to other states might be a good thing from an ethical perspective. We note only that the transfer is a result of the use of market power and therefore the result of a market failure, and that it is a real loss of wealth to the U.S. economy. We leave it to the reader to decide if the wealth transfer is a good or bad thing.

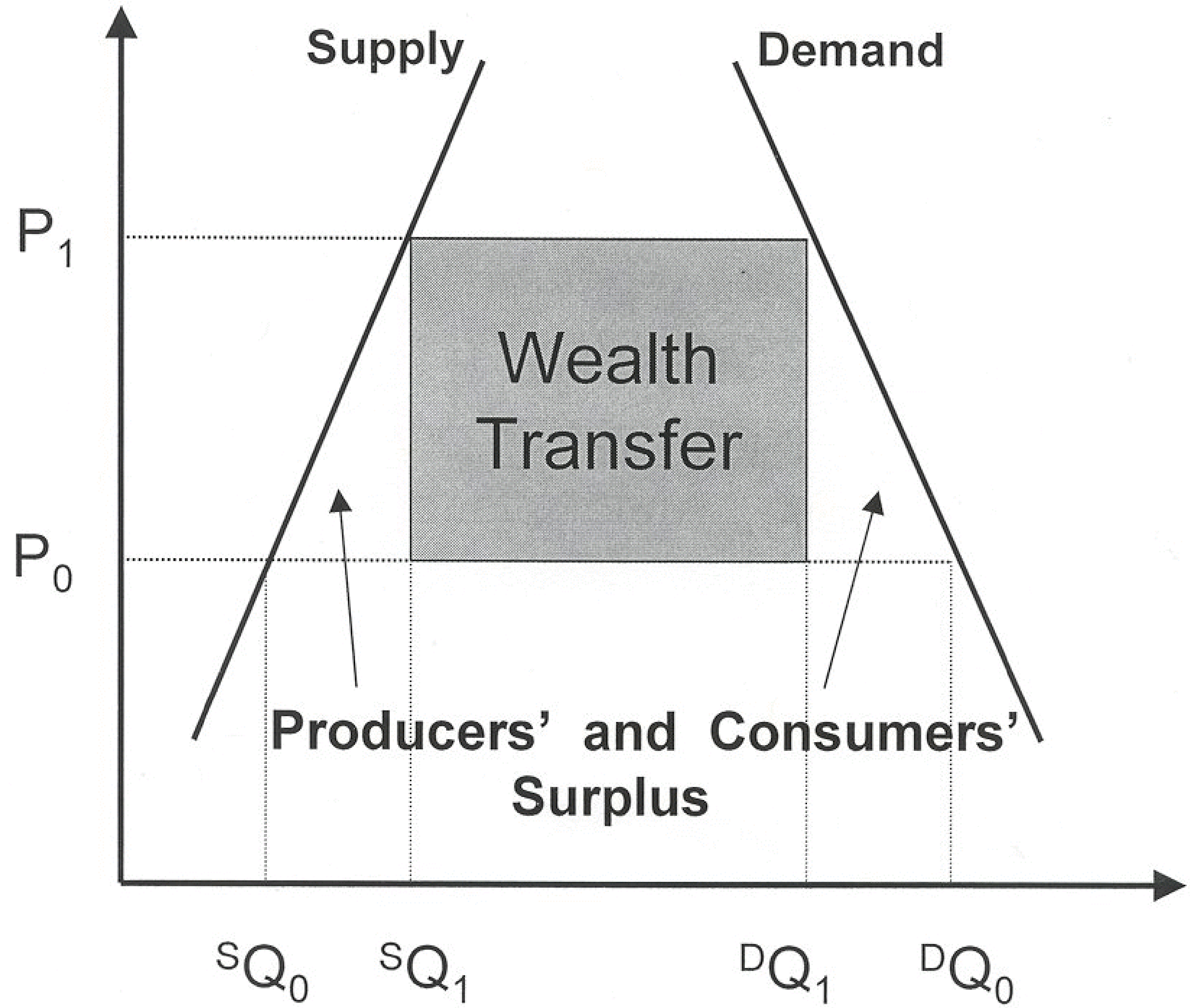
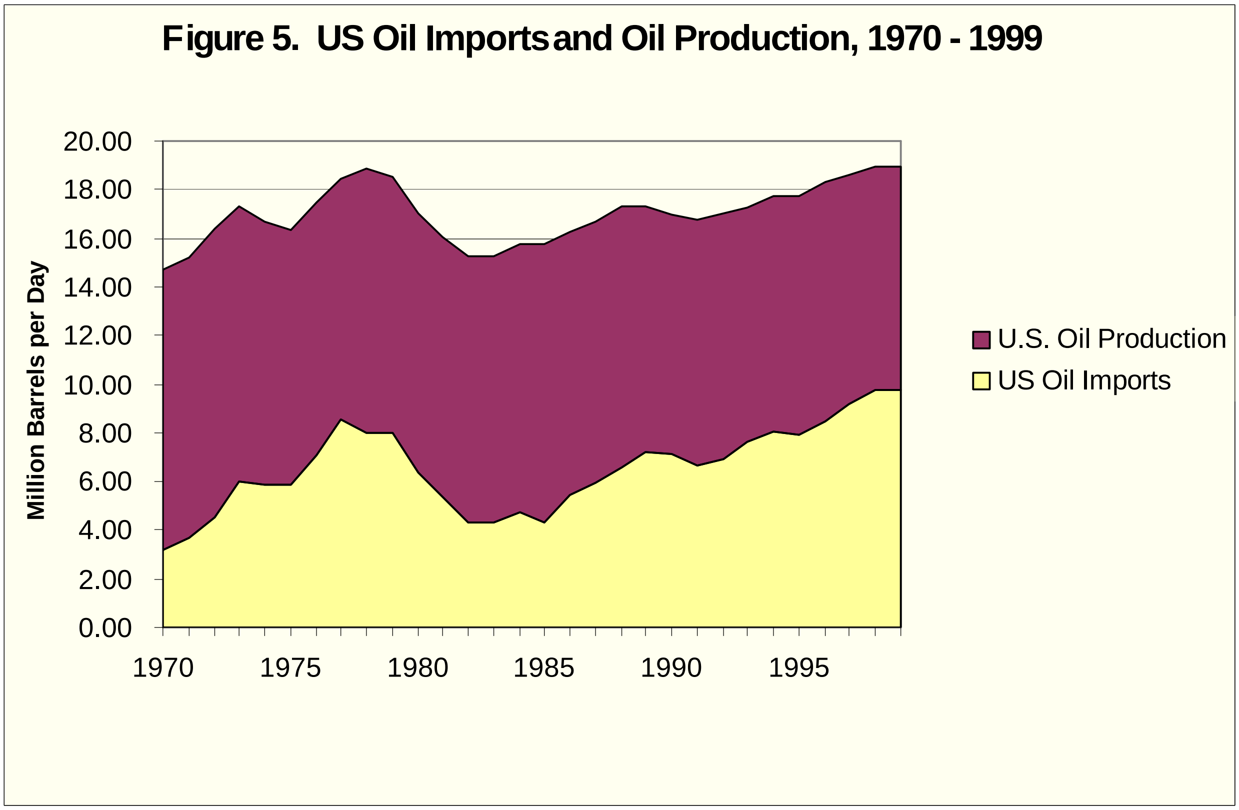


Figure 4. Diagram showing Wealth Transfer and Potential GDP Losses

In 1972, the year before the first oil price shock, imported crude oil cost U.S. refiners an average of $10.86 per barrel in 1998 $ (Figure 2). Simulations of competitive market conditions have produced a variety of price estimates in the general vicinity of $10 per barrel. Greene et al. (1998) cite estimates from four such studies, with a range from $6.86 to $12.19 per barrel (1998 $). Most recently, Berg et al. (1997) simulated OPEC behavior in response to world carbon taxes and concluded that were OPEC to behave as a competitive producer, the world price of oil in 2000 would be $10.90/bbl, in 1994 dollars, or $11.69 in 1998 $. In November and December of 1998, and January and February of 1999, refiner acquisition costs for imported oil fell to $10.99, $9.39, $10.16 and $10.22 per barrel, respectively. A competitive oil price of $11.27 per barrel (1998 $) would imply that market prices briefly fell below competitive market levels in those months.



The wealth transfer in each year t is precisely the quantity of oil imported, Q_{It} , times the difference between the actual price in year t, P_t , and the assumed competitive market price, P_c .

$$W_t = Q_{It}(P_t - P_c) \tag{1}$$

The only source of uncertainty in this calculation is the competitive market price. In the sensitivity analysis discussed below we test three alternatives to a constant competitive market price of $10/bbl. (1992 $): (1) competitive prices rising over time at 1%/year in constant dollars, (2) a higher competitive price of $12/bbl. (1992 $), and (3) a lower competitive price of $8/bbl (1992 $).

3.2 LOSS OF POTENTIAL GDP

Even if domestic factors of production are fully employed, an increase in oil prices above competitive market levels will cause a real income loss, due to the increased economic scarcity of oil. If no substitution for oil were possible in the economy, the loss would exactly equal the "windfall loss", which is the product of the quantity of oil consumption times the change in price. Thus, the increase in the bill is an upper bound on the permanent income loss (Eastwood, 1992, pp. 403-404). This relationship is readily derived, as shown by Bohi (1989, Ch. 3).

Let X be the gross output of the economy including both the final consumption of petroleum products services and the intermediate consumption of crude oil and natural gas liquids, Q.

$$GDP = X - P_O Q \qquad (2)$$

Gross output, X, is a function of inputs of capital, K, labor, L, other energy E, and oil, X=X(K,L,E,Q). Setting the marginal products of these factors equal to the change in GDP yields the following.

$$dGDP = P_K dK + P_L dL + P_E dE - QdP_Q \qquad (3)$$

If no factor substitution is possible then, dK=dL=dE=0, from which it follows that the loss of GDP is exactly equal to $-QdP_Q$. Since some amount of substitution will be possible, the actual loss of GDP will be less, making the windfall loss an upper bound on the GDP loss as Eastwood (1992) has pointed out.

This approach can also be used to derive an upper bound on the elasticity of GDP with respect to the price of oil. First dividing through by GDP and then by dP_Q, and then multiplying by P_Q, results in the following expression in terms of elasticities (ß) and expenditure shares (s).

$$b_{GDP,P_Q} = s_K b_{K,P_Q} + s_L b_{L,P_Q} + s_E b_{E,P_Q} - s_Q \qquad (4)$$

If no substitutions for oil are possible, then all the ß's on the right hand side are zero, leading to the conclusion that the elasticity of GDP with respect to oil price would exactly equal the negative of the oil cost share of GDP. Since substitutions for oil are possible, the oil cost share of GDP is useful only as an indicator of the general magnitude of the oil price effect. Total GDP losses may be larger, due to the existence of macroeconomic adjustment costs, discussed below.

Measuring deadweight losses of consumers' and producers' surplus is a more direct way to calculate the loss of potential GDP resulting from an increase in oil prices above competitive market levels. In oil markets, these losses can be measured by the triangular areas under the demand and supply curves from the competitive market price (P_0) to the current price of oil (P_1) and between Q_0 and Q_1, as shown in Figure 4 (and derived mathematically in equation (A.2) of Appendix A.[3] The deadweight consumers' surplus loss does not include the rectangles equal to the change in quantity times the competitive market price [$(Q_1 - Q_0) P_0$], since that amount would have been spent at the competitive market price.

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[3]Strictly, consumers' surplus is the area under the Hicksian, or compensated demand curve, whereas the available econometric evidence pertains to Marshallian, uncompensated demand curves. Since the area under the Hicksian demand curve is an upper bound on the area under the Marshallian demand curve, estimates of deadweight surplus loss based on Marshallian curves will underestimate the true deadweight loss of consumers' surplus (e.g., Varian, 1992, p. 168).

If oil supply and demand curves were static, the estimation of total welfare loss would be a simple matter of calculating the areas of the two deadweight loss triangles. But oil supply and demand are inherently dynamic, with long-run price responses about ten times as great as short-run responses. Furthermore, the ramifications of oil price increases extend beyond oil markets into other markets, where additional losses (and gains) can occur. Without a general equilibrium representation of the national economy, however, the full net deadweight losses in all markets cannot be calculated. In general, it is reasonable to assume that economy-wide deadweight losses will exceed the deadweight losses in the oil market alone. In this sense, the oil market welfare losses constitute a *lower* bound on the GDP losses.

The fact that oil markets adjust dynamically to changes in oil price is critically important to correctly estimating the deadweight welfare losses. The fact that long-run price slopes may be ten time as large as short-run price slopes implies that welfare losses from a given price increase will grow over time. Suppose that U.S. aggregate oil demand is given by the following equation,

$$Q_t = A + BP_t + cQ_{t-1} \tag{5}$$

where P_t is the price of oil in time period t, A is a constant, B the short-run price slope, and (1-c) is the dynamic adjustment rate.

Now suppose that the price of oil increases from an initial level of P_o at time t=0 to a new higher level P_1 at t=1. Integrating under the demand curve to calculate the consumers' surplus loss after 1 period, we obtain the following formula for the consumers' surplus loss triangle (for details, see the appendix).

$$CS = -\frac{1}{2} B(P_1 - P_o)^2 \tag{6}$$

However, if the price remains at P_1 indefinitely, the long-run consumers' surplus loss is given by the following equation.

$$CS = -\frac{1}{2}\frac{B}{1-c}(P_1 - P_o)^2 \tag{7}$$

Note that B/(1-c) is exactly the long-run price slope. Because the value of c in lagged adjustment models is typically about 0.9, the long-run consumers' surplus loss is approximately ten times as large as the short-run (single period) loss.[4] An analogous argument applies for producers' surplus loss and the supply equation.

[4]This assumes that the price change remains constant. In fact, in this example, other things equal, one would expect price to fall as the long-run adjustment decreased demand. This would mitigate the ten-fold increase in consumers' surplus loss.

In reality, prices fluctuate continuously making things much more complicated. Still, consumer and producer surplus losses versus an assumed competitive market price can be calculated for dynamic demand and supply equations. The loss in any given year turns out to depend on the entire history of price changes and could, in principle, become a gain if prices somehow fell below the competitive market level. The formula used is more complex, but can be readily computed from historical prices and quantities.

$$CS = -\frac{1}{2}B\sum_{i=0}^{T-1} c^i (P_o^2 - P_{T-i}P_o + P_T P_{T-i} - P_T P_o) \qquad (8)$$

The derivation of this formula is provided in detail in the appendix. P_T is the price of oil in the current year T (the year for which the consumers' surplus loss is being computed), while i indexes the years between the initial year t=0 and T. The calculation of producers surplus is exactly analogous, except with the opposite sign. The sum of dynamic producers' and consumers' surplus in each year constitutes a lower-bound estimate on the loss of GDP because welfare losses outside of the oil market are ignored.

3.3 MACROECONOMIC ADJUSTMENT LOSSES

The processes by which macroeconomic models estimate the impacts of oil price shocks on GDP have been well described by Huntington (1996, p. 2). His discussion of how models represent oil price shock impacts is a good summary of the theory of how they work in the real economy.

> "Energy costs are a common input for all sectors of the economy. In the models, firms pass throught the higher material costs to the prices of final goods. Labor tries to raise wages to cover the increased cost of living. This short-run burst in costs raises the economy's aggregate price level. Without an expansion in the money supply, real money balances – the money supply adjusted for the price level – decline. Interest rates swing upward, discouraging investment, and through the multiplier effect, output.
>
> " As unemployment spreads, the pressures on costs subside over time. Labor becomes less aggressive in seeking wage increases. As long as accommodating monetary and fiscal policies are not used, the price level within the economy would begin to retreat, allowing aggregate output to rebound. In the case of a permanent energy price shock, potential of full-employment output would be less."

The key elements of Huntington's analysis are, (1) that macroeconomic adjustment losses are the result of increased unemployment of resources in the economy, (2) that the effects are temporary, and (3) that monetary policy plays a role either by accommodating oil price shocks, at the expense of greater inflation, or not, resulting in greater unemployment.

Without using a macroeconomic model, we can still estimate the macroeconomic adjustment costs of oil price shocks by using elasticities derived from model simulations carried out by the Energy

Modeling Forum (EMF) (Hickman et al., 1987). The results of the EMF analysis were critically reviewed by Eastwood (1992), who provides more complete discussion of the three sources of economic losses and their context in economic theory. The EMF study used 14 economic models to measure the effect of a 50% rise in oil prices occurring in 1982. The median estimate of annual GDP loss over the next four years was 2.3%, implying an elasticity of about -0.046. While most of the models used do not separate the potential GDP loss from the macroeconomic adjustment loss, three of the four models that do provide separate estimates allocate more than 70% of the effect of a price shock to the macroeconomic adjustment loss. Since macroeconomic adjustment costs should decline over time while potential GDP losses should increase, it is reasonable to expect that the macroeconomic share in the earlier years exceeds the average of 70%.

Macroeconomic adjustment costs are estimated by means of an *ad hoc* method that relies on four key assumptions: (1) the value of the oil price elasticity of GDP, (2) the share of the total oil price impact attributable to macroeconomic costs, (3) the proportionality of macroeconomic adjustment impacts to the oil cost share of GDP, and (4) a method for simulating the rate of adjustment of the economy to higher oil prices. The median elasticity estimate from Hickman's (1987) study of -0.046 is assumed to apply in 1982. The importance of oil to the U.S. economy was near its peak during the time period chosen for the EMF study. For all other years the total elasticity of GDP with respect to oil price is assumed to equal -0.046 multiplied by the ratio of the oil cost share of GDP in that year to the oil cost share in 1982. Thus, in 1998 when the oil cost share of GDP was 0.01, the elasticity of GDP with respect to oil price would be -0.046(0.01/0.055) = -0.0084. The macroeconomic share of the total GDP elasticity is assumed to be 90%, in the first year.

To simulate the economy's adjustment to an oil price shock an analogy is made to the lagged adjustment of oil supply and demand. The dynamic adjustment oil demand equation shown in (5) implies that there is an ideal price (P_t^*), not necessarily equal to the actual price, to which the economy has adjusted at any particular time. In the context of the linear lagged adjustment model of (5), the ideal price at time t is a weighted average of the current market price and last period's ideal price.

$$P_t^* = cP_t + (1-c)P_{t-1}^* \tag{9}$$

In the oil supply and demand equations, c = 0.1 has been used as a typical value. Since it is believed that the wages, prices and interest rates adjust more rapidly than petroleum demand, a value of c = 0.25 is used to compute the price to which the economy has adjusted for the purpose of estimating macroeconomic adjustment costs. As an illustration, if the price of oil jumped from $10/bbl to $20/bbl, the adjusted price would be $12.50 after the first year, $14.38 after the second and $17.63 after the fifth year, implying that three fourths of the effects of the shock had dissipated by that time. Macroeconomic adjustment costs equal the difference between the actual and ideal (or adjusted price) divided by the midpoint of the two prices multiplied by the current elasticity of GDP with respect to the price of oil. Alternative adjustment rates are tested in a sensitivity analysis of oil dependence costs.

$$\frac{(P_t - P_t^*)}{\left(\frac{P_t + P_t^*}{2}\right)} \cdot b_t \cdot 0.9 \cdot s_t = \textit{Macroeconomic Adjustment Loss} \qquad (10)$$

4. DATA

Four key data items are required to compute the oil dependence costs described above. The first, and most straightforward are the prices and quantities of petroleum produced and consumed by the United States, OPEC and rest-of-world from 1970 to 1999. Petroleum is defined to include crude oil, lease condensate and natural gas plant liquids, but prices are based on U.S. refiners' acquisition cost of crude oil only. Detailed data sources can be found in appendix B. Second, estimates of U.S. petroleum supply and demand curves are needed to estimate consumer and producer surplus losses. These estimates are discussed below. Third, an estimate of the oil price elasticity of GDP is needed. Several are available in the literature and from a thorough analysis of energy-economic models by the Energy Modeling Forum (Hickman et al., 1987). The range and central tendency of these estimates is also discussed below. Fourth, a counterfactual estimate of a competitive world oil market price is needed to estimate wealth transfer and potential GDP effects.

4.1 EMPIRICAL ESTIMATES OF PRICE SLOPES AND ADJUSTMENT RATES OF OIL SUPPLY AND DEMAND IN THE UNITED STATES

U.S. petroleum demand is price inelastic, even in the long-run. Greene et al. (1995) reviewed studies by Suranovic (1994), and Huntington (1994, 1993), including Huntington's analysis of eleven world oil market models, and found short-run (one-year) price elasticities ranging from -0.027 to -0.116, and long-run elasticities ranging from -0.157 to -2.544. They settled on "typical" values based on Huntington (1993) of -0.06 for the short-run and -0.60 for the long-run elasticities at a world oil price of $35.20/bbl in 1993 dollars, or $38.67/bbl in 1998 dollars. Gately and Rappoport (1988) tested several functional forms against U.S. oil demand data from 1949-1985. Constant price elasticity formulations yielded long-run elasticity estimates in the range -0.3 to -0.4. A linear, variable elasticity form, which Gately found neither better nor worse than the constant elasticity forms, implied a long-run price elasticity of -0.72 at the 1985 oil price (approximately $40/bbl in 1998 dollars) and -0.27 at half the 1985 price level. Dargay and Gately (1994) found U.S. oil demand to be similarly inelastic, particularly in the transportation sector, even when asymmetric price responses were taken into account.

A review of U.S. oil supply price elasticities in ten models by Huntington (1991) found a range of short-run elasticity estimates from 0.0 to 0.137, with an average or 0.052. Long-run elasticities of oil supply ranged from 0.162 to 0.662, with an average of 0.394. The American Petroleum Institute (Porter, 1992) constructed a model of U.S. petroleum supply and simulated the impacts of three oil price regimes ($15, $20, and $25/bbl) over a twenty year period from 1990 to 2010. Over twenty years, the increase in price from $15 to $25/bbl resulted in an estimated rise in 2010 U.S. oil supply of 15.6%, for an implied price elasticity using the midpoint formula of +0.29. Given the 20-year time horizon, this may be assumed to be very close to a long-run price elasticity of U.S. oil supply. Gately (1995) assumed a short-run U.S. supply elasticity of +0.05 with a lagged supply coefficient of 0.95, implying a long-run supply elasticity of 1.0.

The conclusions of Greene et al. (1995) concerning oil supply and demand elasticities, which are based principally on the findings of Huntington (1991; 1994), are adopted here. Because the supply and demand equations used in the cost calculations are linear, elasticities increase with increasing price, as shown in Table 1. Assuming lagged quantity coefficients of 0.9, the long-run elasticity estimates would be exactly ten times as large.

Table 1. Short-Run Elasticities of U.S. Petroleum Supply and Demand at Various Prices

Price (97$/BBL)	Demand MMBD	Elasticity	Supply MMBD	Elasticity
$20	17.10	-0.038	9.68	0.028
$28	16.84	-0.054	9.79	0.039
$35	16.60	-0.069	9.88	0.049

The sensitivity of GDP to changes in the price of oil is the most critical parameter in this analysis. It is convenient to summarize this relationship in terms of the elasticity of GDP with respect to the price of oil, a dimension-less coefficient equal to the percent change in GDP for a 1% change in the price of oil. Fortunately, a great many estimates of this elasticity are available in the literature (Table 2).

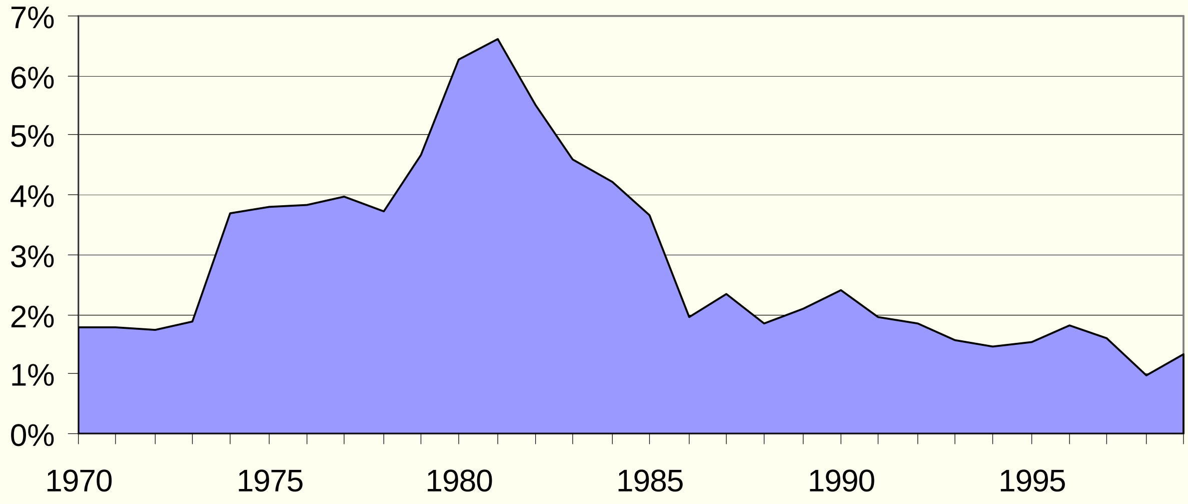
The estimates of GDP elasticity with respect to oil price presented in Table 2 appear to correlate with the oil cost share of GDP for the period covered by the study. In particular, estimates pertaining to the 1979–1985 period show the highest oil price impacts. Clearly this indicator of the importance of oil to the economy has decreased substantially since 1982 (Figure 6). Oil price impacts also depend on the substitutability of oil in the economy, and it is less clear what can be said about that factor. Since the decade of 1972-82, oil use has become much more concentrated in the transportation and industrial sectors, with the nearly totally oil dependent transportation sector being the only one whose oil use has increased. If oil substitutability is lower in these two sectors than in the utility and residential/commercial buildings sector, as is suggested by their continuing reliance on oil, then the overall substitutability of oil in the economy may have decreased, increasing the importance of oil to the economy (Santini, 1992). In the estimation below, we scale the elasticities of GDP with respect to oil prices by the oil cost share of GDP but make no attempt to account for the greater concentration of oil use in the most oil dependent sectors.

Most recently, the U.S. Energy Information Administration (2000) estimated that the 1998–99 doubling of world oil prices from $11 to $22 per barrel would produce a -0.50 percent change in GDP in 1999 and a -1.00 percent change in 2000. The difference is due an expected time lag for the full impact of the oil price change to be felt. The implied elasticity of -0.01 is only about one-fourth to one-fifth as large as the other estimates cited in Table 2. It is, however, consistent with the rule of thumb of scaling the elasticity to the oil cost share of GDP, since the oil cost share of GDP was only 1.0% in 1998.

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

Source	Time Period	GDP Elasticity
Pindyck (1980)	before 1980	-0.02
Mork & Hall (1980)	1973-77	-0.03
Rasche and Tatom (1981)	1949-78	-0.07
Darby (1982)	1957:1-1976:4	-0.021
Hamilton (1983)	1973-80	-0.231
Gisser and Goodwin (1986)	1961:1-1982:4	-0.11
Hickman, Huntington & Sweeney (1987)		
median of 14 models	1982-86	-0.046
average of 14 models	1982-86	-0.055
Ram and Ramsey (1989)	1948-85	-0.069 to -0.074
Mork (1989)	1970-88	-0.144 (price increases only)
U.S. DOE (1990)	Forecast	-0.02 to -0.04
Heilke (1991)	Simulation	-0.03 to -0.04
Mory (1993)	1951-90	-0.055
	1952-90	-0.067(price increases only)
Smyth (1993)	1952-90	-0.052 (for price increases above the historical maximum, only)
Mork, Olsen & Mysen (1994)	1967:3-1992:4	-0.054 to -0.068
U.S. DOE/EIA (2000)		-0.01

Figure 6. Oil cost share of GDP, 1970 - 1999



5. RESULTS

The estimated costs of oil dependence to the U.S. economy (wealth transfer plus macroeconomic adjustment and potential GDP losses) from 1970 to 1999 add up to $3.4 trillion in undiscounted 1998 dollars, but $7.0 trillion when the past losses are reckoned at their present value (using a 4.5% discount rate). In this paper, the undiscounted costs will be reported unless indicated otherwise. However, the present value of past losses is the more correct indicator of cumulative economic loss viewed from the present time. A dollar lost ten years ago will reduce the rate of economic growth from that time forward. Assuming a real rate of interest of 4.5%, a dollar ten years ago would have a present value of $1.55. On the other hand, present valuing losses compounds the timing and magnitude of losses. The longer ago a loss occurred, the larger it appears. Undiscounted losses eliminate the timing issue, but understate the true economic losses. Although most of the estimates presented below are denominated in undiscounted 1998 dollars, the true cost of these losses to the economy today is much greater, due to the lost opportunity for additional economic growth.

Of the estimated $3.4 trillion of undiscounted economic losses, the largest component is potential GDP loss, at $1.8 trillion, or 43%. Wealth transfer is the second largest component at $1.3 trillion (31%). Macroeconomic adjustment losses are estimated to come in third, at $1.1 trillion (26%). These estimates should be considered very approximate, and indicative of the general magnitudes of oil costs rather than precise measurements. The methods used produce estimates that are not likely to be wildly exaggerated, but also cannot be considered exact.

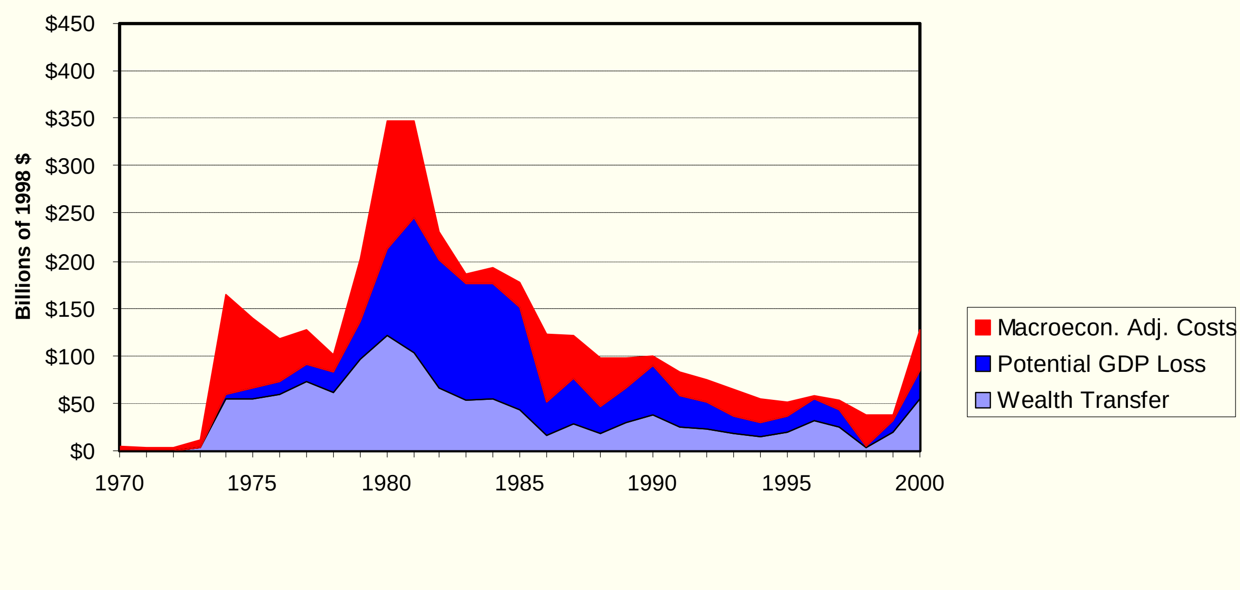
The greatest economic damage was done during the first half of the 1980s, a period in which oil prices surged to a peak of over $60 per barrel in 1981 (1998 $). In the estimates presented here (Table 3, Figure 7) the oil crisis of 1973-74 appears to have had a much smaller economic impact, although it is remembered as a time of crisis and disruption. This may be partly due to the shock caused by the unexpected and dramatic demonstration of market power by Arab members of OPEC. It was also likely due to the oil price controls in the United States, which exacerbated the impacts of the world oil price increases by creating fuel shortages within the U.S. The cost-estimation methods used here make no attempt to reflect the unique circumstances of the first oil price shock. It is worth noting, as well, that U.S. GDP in 1973 (in constant dollars) was only half as large as in 1999, so that a $150 billion loss was twice as significant, relative to GDP, as it is today.

The estimated macroeconomic adjustment losses are the most volatile of the three components, peaking in the years following sudden price changes: (1) 1974-75, and (2) 1979-81, but also during the price collapse of 1986. The reason for this is the rate at which macroeconomic adjustments are assumed to occur. Under base case assumptions, a 25% adjustment will be made in the first year, 44% in the second, 58% in the third, and by the fifth year more than three fourths of the shock will have dissipated. Historically, prices have tended to trend downward after the first or second year of a price shock, which closes the gap more rapidly between prevailing market price and the price to which the economy has adjusted.

Table 3. Base Case Estimates of Oil Dependence Costs

Year	Actual Price 1998 $	Competitive Price 1998 $	Potential GDP Loss Bill $ 1998	M acro-Econ Adj. Loss Bill $ 1998	Wealth Transfer Bill $ 1998	Total Economy Loss	U. S. GDP 1998 $	U. S. Oil Consumpt (Millions of Barrels per Day)	U. S. Oil Imports
1970	$10.94	$10.94	$0	$5	$0	**$5**	$3,824	14.70	3.16
1971	$11.15	$11.15	$0	$3	$0	**$3**	$3,829	15.21	3.70
1972	$10.85	$10.85	$0	$4	$0	**$4**	$3,955	16.37	4.52
1973	$13.03	$11.27	$0	$7	$4	**$11**	$4,172	17.31	6.03
1974	$36.67	$11.27	$6	$104	$55	**$164**	$4,413	16.65	5.89
1975	$37.30	$11.27	$11	$74	$56	**$140**	$4,385	16.32	5.85
1976	$34.10	$11.27	$14	$45	$59	**$118**	$4,365	17.46	7.09
1977	$34.52	$11.27	$19	$37	$73	**$129**	$4,601	18.43	8.57
1978	$32.26	$11.27	$21	$18	$61	**$101**	$4,816	18.85	8.00
1979	$44.22	$11.27	$41	$66	$96	**$203**	$5,074	18.51	7.99
1980	$63.30	$11.27	$92	$134	$121	**$347**	$5,218	17.06	6.37
1981	$63.25	$11.27	$143	$101	$102	**$347**	$5,201	16.06	5.40
1982	$53.88	$11.27	$135	$30	$67	**$231**	$5,320	15.30	4.30
1983	$45.13	$11.27	$122	$11	$53	**$186**	$5,207	15.23	4.31
1984	$42.87	$11.27	$121	$17	$54	**$192**	$5,413	15.73	4.72
1985	$38.73	$11.27	$108	$27	$43	**$178**	$5,792	15.73	4.29
1986	$19.58	$11.27	$34	$72	$16	**$123**	$5,999	16.28	5.44
1987	$24.60	$11.27	$47	$46	$29	**$122**	$6,184	16.67	5.91
1988	$19.06	$11.27	$27	$52	$19	**$98**	$6,366	17.28	6.59
1989	$22.71	$11.27	$37	$31	$30	**$98**	$6,609	17.33	7.20
1990	$26.18	$11.27	$50	$11	$39	**$100**	$6,831	16.99	7.16
1991	$21.64	$11.27	$34	$25	$25	**$83**	$6,915	16.71	6.63
1992	$20.51	$11.27	$28	$23	$23	**$75**	$6,851	17.03	6.94
1993	$17.71	$11.27	$19	$28	$18	**$64**	$7,037	17.24	7.62
1994	$16.64	$11.27	$14	$25	$16	**$55**	$7,200	17.72	8.05
1995	$17.96	$11.27	$17	$15	$19	**$51**	$7,450	17.73	7.89
1996	$21.24	$11.27	$24	$3	$31	**$58**	$7,620	18.31	8.50
1997	$18.71	$11.27	$19	$9	$25	**$53**	$7,882	18.62	9.16
1998	$12.08	$11.27	$3	$32	$3	**$38**	$8,192	18.92	9.76
1999	$17.06	$11.27	$12	$5	$21	**$38**	$8,801	19.23	9.75
2000*	$25.74	$11.27	$30	$43	$55	**$128**	$9,157	19.62	10.45
* Projected									

Figure 7. Oil Dependence Costs to U.S. Economy, 1970 - 2000



Wealth transfer costs are immediate and change simultaneously with price changes. The long-run nature of potential GDP losses versus short-run macroeconomic adjustment costs can be seen in the lag between the two. Macroeconomic loss estimates spike at $104 billion in 1974, the first full year of the first oil price shock in 1973-74. Potetential GDP losses in that same year are estimated to be only $6 billion. A second spike in adjustment costs can be seen in 1979-81, during the oil price shocks associated with the Iran-Iraq War. Potential GDP loss estimates increase continuously from 1974 to 1981, and then decline through the price collapse of 1986.

The fact that the three cost components do not move in concert, and sometimes move in opposition, can lead to confusion about the impacts of oil prices on the economy. An important feature of sudden price declines (such as occurred in 1986 and recently in 1998) is that macroeconomic adjustment losses increase at the same time that potential GDP losses decrease. [5] Thus, in 1986, it is estimated that the increase in macroeconomic adjustment losses was more than offset by a sharp reduction in Potential GDP losses (and also wealth transfer). Total estimated costs fell by $55 billion. This tendency for macroeconomic and potential GDP effects to offset each other in a sharp price decline has been noted by several economists (e.g., Hamilton, 1996; Mork, 1989 and 1994; Greene and Leiby, 1993, p. 40; Hooker, 1996). The sudden drop in oil prices in 1998 apparently generated an estimated $32 billion in macroeconomic adjustment costs but these were more than offset as wealth transfer and potential GDP losses very nearly went to zero. In the following year, when oil prices rebounded, the reverse occurred: macroeconomic losses dropped to $5 billion and were replaced by $12 billion in potential GDP losses and $21

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[5]The decrease in oil price expands the productive potential of the economy. However, a sudden decrease in price is still a price shock and produces macroeconomic adjustment losses, as would a sudden increase in price.

billion in wealth transfer. The reason for this is that the rebound brought the price level back to the ideal price level to which the economy had adjusted. The estimated total economic costs in 1998 and 1999 were the same: $32 billion.

The important implication of the offsetting cost components is that the price increase of 1999 should not have a noticeable impact on GDP in 1999. This might easily lead an observer to incorrectly conclude that the economy was no longer sensitive to oil prices. The impact of the price rise in 1999 appears to have been obscured by the coincidental dynamics of the three cost components, as noted above. If prices remain at $26/barrel in 2000, all three types of losses will increase in 2000 adding up to a total loss of $128 billion. The estimated economic impact amounts to roughly a 1% decrease in the rate of GDP growth in 2000.

5.1 SENSITIVITY ANALYSIS

The estimates of oil dependence costs over the 1970 to 1999 period rely on several key parameters. Eight critical parameters were varied to create 14 sensitivity cases to test the degree to which cost estimates depended on their assumed values. Changing one parameter at a time produced a range of total economic cost estimates from $2.9 trillion to $4.1 trillion (undiscounted 1998 $). Two extreme cases were created by combining all parameter values that tended to reduce costs into one set, and all those that tended to increase the cost estimates into another. This produced a much wider range of cost estimates: from $1.7 to $7.1 trillion (again, undiscounted 1998 dollars).

Potential GDP losses and especially the transfer of wealth are sensitive to the assumed competitive market world oil price. Indeed, the transfer of wealth is precisely the quantity of oil imported times the difference between the actual price and the competitive price. Potential GDP losses are dependent on the competitive price since consumers' and producers' surplus calculations integrate under the demand and supply curves from the competitive price to the actual prices. The Base Case assumption is that the competitive market price of oil would be $10/barrel in 1992 dollars ($11.27/barrel in 1998 dollars). This assumption suggests that oil price fell briefly below competitive market levels in November and December of 1998, and January and February of 1999. In those months, refiner acquisition costs for imported oil fell to $10.99, $9.39, $10.16 and $10.22 per barrel, respectively.

Assuming a competitive market price of $12 per barrel (1992 $) reduces the estimated total economic costs from $3.4 to $3.0 trillion (1998 $). Wealth transfer losses come down from $1.2 trillion to $1.0 trillion and estimated potential GDP losses are reduced from $1.2 to $0.9 trillion.

Both macroeconomic adjustment and potential GDP losses are sensitive to the rates with which the economy is assumed to adjust to oil price changes. There is greater uncertainty about the rate of macroeconomic adjustment to price shocks, however, because little empirical evidence is available. Each of these key parameters was varied individually, and then all simultaneously to determine the sensitivity of the oil dependence cost estimates to key parametric assumptions. Finally, it is reasonable to argue that whatever oil prices might have done over the past 30 years, they would not have remained absolutely constant. We also estimate economic costs for several random price series whose mean is equal to the competitive world oil price.

Table 4. Economic Costs of Oil Dependence for Fourteen Sensitivity Cases, in Trillions of Undiscounted 1998 Dollars (Components may not add to totals due to rounding)

CASE	Wealth Transfer	Potential GDP Loss	Macro-economic Adjustment	TOTAL
Base Case	1.2	1.2	1.1	3.4
Constant GDP Elasticity	1.2	1.2	1.7	4.1
Lower GDP Elasticity	1.2	1.2	0.6	2.9
Higher GDP Elasticity	1.2	1.2	1.6	4.0
Slower Macro. Adjust. Rate	1.2	1.2	1.6	3.9
Faster Macro. Adjust. Rate	1.2	1.2	0.8	3.2
Lower Macro. Cost Share	1.2	1.2	0.8	3.2
Lower Oil Market Elasticity.	1.2	0.9	1.1	3.1
Higher Oil Market Elasticity	1.2	1.6	1.1	3.8
Higher Competitive Oil Price	1.0	0.9	1.1	3.0
Lower Competitive Oil Price	1.3	1.5	1.1	3.9
1%/yr. Competitive Price Incr.	1.0	1.0	1.1	3.1
All Cost-lowering Assumptions	0.9	0.5	0.3	1.7
All Cost-raising Assumptions	1.3	2.0	3.8	7.1

Although most resource economists now agree that the Hotelling model of resource depletion does not apply to oil (Watkins, 1992), it is still interesting to see how estimated costs change if one assumes that the competitive price of oil would have increased over time at an exponential rate, as implied by Hotelling resource depletion theory. If one assumes an annual rate of increase as high as 2%, then the competitive price of oil in 1999 would be $20 per barrel. Of course, this would imply that prices throughout all of 1998 and most of 1997 and 1999 were below competitive market levels. This is not impossible, since a monopolist can overproduce if it wishes, and this may even be a good strategy for bankrupting competitors in certain circumstances. If one discounts this as unlikely, however, a rate of price increase of 1% would appear to be more reasonable, leading to a competitive price in 1999 of $15 per barrel. Under this assumption, estimated total costs decrease from $3.4 trillion to $3.1 trillion.

Macroeconomic adjustment cost estimates are sensitive to the overall elasticity of GDP with respect to the price of oil, and with respect to whether the GDP elasticity is assumed to remain constant, or to change in proportion to the oil cost-share of GDP. From the Base Case elasticity estimate of -0.046, alternative oil price elasticities of -0.025 and -0.07, were tested. Values such as these can be found in the empirical literature (see e.g., Table 2). Reducing the price sensitivity of GDP affects only the estimated macroeconomic adjustment costs, since the potential GDP losses are calculated as the consumer and producer surplus losses under the oil supply and demand curves. The lower value of -0.025 reduces total estimated costs from $3.4 trillion to $2.9 trillion, and estimated macroeconomic adjustment losses from $1.1 trillion to $600 billion. Assuming the higher price elasticity of -0.07 increases total estimated losses to $4 trillion. In both cases, the GDP elasticities are assumed to vary with the oil cost share of GDP.

In the Base Case, it is assumed that 90% of the initial year's GDP losses are due to macroeconomic losses and only 10% to potential GDP losses. This is intended to reflect the fact that potential GDP losses adjust slowly and that, as is demonstrated in the appendix, the long-run potential GDP loss due to a price shock will be approximately 10 times the short-run, one-year loss. An alternative value of 70% for macroeconomic losses in the first year was tested. Macroeconomic adjustment costs fell from $1.1 trillion to $0.8 trillion and total costs consequently decreased to $3.2 trillion. Faster and slower rates of adjustment for macroeconomic adjustment losses were assumed. A faster rate of adjustment implies that the ideal price to which the economy has adjusted will converge more rapidly on the actual market prices, and the impacts of an oil price shock will be shorter lived. Increasing the speed of adjustment to 0.33 from 0.25 reduced macroeconomic adjustment losses to $0.8 trillion. Decreasing the rate of adjustment to 0.15 increased losses to $1.6 trillion.

Macroeconomic GDP impacts also depend strongly on whether the price elasticity of GDP is assumed to be constant over time or proportional to the oil cost-share of GDP. In the Base Case, it is assumed that the oil price elasticity of -0.046 applies to the year 1983, close to the peak year for oil cost share as a percent of GDP. Thus, in nearly all other years the oil price elasticity of GDP is smaller, sometimes as low as -0.01, as the oil cost shares in Figure 6 indicate. In the constant elasticity sensitivity case it is assumed that the oil price elasticity of GDP remains constant at -0.046. This change affects only the macroeconomic adjustment costs, since the potential GDP losses are directly computed from the dynamic oil supply and demand curves and the transfer of wealth is calculated independently from the quantity imported and the actual and assumed competitive oil prices. In the constant elasticity case, macroeconomic costs rise to $1.7 trillion, pushing total economic costs to $4.1 trillion.

6. CONCLUSIONS

Even over a period as long as thirty years, economic costs on the order of $3.4 trillion ($7.1 trillion present value) constitute a serious national problem. For comparison, the sum of total outlays for national defense from 1970 to 1999 was more than twice as large, $8.9 trillion (1998 $). Total net interest payments by the federal government were of the same general magnitude, $4.6 trillion (U.S. Census Bureau, 1999, table 543). The present value of these past losses amounts to $7 trillion, almost an entire year's GDP. Significant oil price shocks preceded every recession of the past three decades and every one of the three significant oil price spikes was followed by a recession. Clearly, oil dependence ranks among the most significant economic problems the United States has faced over the past thirty years.

Over the past decade, oil dependence costs have been declining, reaching their lowest level in 1998 when oil prices hit bottom at under $10/bbl. This led many experts to conclude that oil dependence was no longer a problem, a view not shared by the public. The near tripling of oil prices since then has proven the public right. If oil prices continue at present levels through the end of 2000, it will cost the U.S. economy roughly 1.3% of GDP.

Any accounting of costs such as this begs the question, "What can be done?" Use of the Strategic Petroleum Reserve and oil taxes are frequently mentioned options. Certainly the Strategic Petroleum Reserve can be an important defense against future price shocks. But analyses have shown that the SPR can be effective only against short-lived supply disruptions. According to two studies, the SPR would have to be 30 times larger to make up for supply reductions of the size seen in 1973-74 or 1979-80 (Suranovic, 1994; Greene et al., 1998). Heavily taxing motor fuels, as many OECD countries do, can impose a continuing burden on the economy and is only partially effective against the exercise of monopoly power. The real solution lies elsewhere, in creating new energy options and new transportation technologies.

The ultimate solution to oil dependence lies in changing the fundamental factors that give the OPEC cartel market power and create the United State's oil dependence problem. The U.S. must reduce it's oil consumption and, by means of research, development, and meaningful policies, create low-cost alternatives to petroleum, enhance the recovery of both conventional and unconventional oil resources, and advance energy efficient technologies for transportation. Technological advances in oil exploration and development have been a factor in keeping petroleum prices low during the 1990s (Anderson, 1998). New technology for producing ethanol from cellulosic biomass at perhaps half the cost of older fermentation and distillation processes would be worth billions in reduced oil dependence costs, according to a study published this year (Gallagher and Johnson, 1999). Advanced automotive technology being developed by the Partnership for a New Generation of Vehicles would increase the ability to respond to a gasoline price shock by 50%, according to a recent analysis (Greene, 1997), saving the economy billions of dollars annually (Schock et al., 1999). Cleaner distillate fuels produced from natural gas could reduce emissions from diesel engines and help to undermine OPEC's market power.

Achieving such results is likely to require a significantly greater commitment in resources and resolve. The past costs of oil dependence suggest that a greater commitment would be justified.

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APPENDIX A

ESTIMATION OF THE LOSS OF POTENTIAL GDP BY CONSUMERS' AND PRODUCERS' SURPLUS IN THE DOMESTIC OIL MARKET

APPENDIX A: Estimation of the Loss of Potential GDP by Consumers' and Producers' Surplus in the Domestic Oil Market

Consumers' surplus can be measured by the area under the demand curve from the initial price (here the competitive market price) to the current price level, minus the rectangle representing the change in expenditures. If the demand curve is linear, consumers' surplus is the triangular area shown in Figure 4. This notion is perfectly adequate for a static demand situation. However, if demand is dynamic, and if long-run elasticities differ from short-run elasticities, the question naturally arises, under what demand curve should one integrate? The subject of measurement of consumers' surplus for demand changes that take a significant period of time to be completed, has apparently received very little theoretical or empirical attention (Dargay and Goodwin, 1995). Recently, Dargay and Goodwin showed how consumers' surplus could be computed for dynamic adjustment demand equations, in the case of a one-time price increase persisting for a certain length of time. Here, we show how consumers' and producers' surplus can be estimated for dynamic demand and supply equations when prices are continuously varying, as they are in oil markets.

Consider a simple lagged adjustment, dynamic demand model, in which quantity demanded is a function of the price of oil, a (time varying) constant term, and the lagged value of consumption.

$$Q_t = A_t + BP_t + cQ_{t-1} = \sum_{i=0}^{t-1} c^i A_{t-i} + B\sum_{i=0}^{t-1} c^i P_{t-i} + c^t Q_o \qquad \text{(A.1)}$$

By repeatedly substituting for the lagged quantity term it becomes clear that, at any given time, the dynamic demand curve is a function of all past prices as well as the current price. This demand curve with many prices can be integrated, given a suitable parameterization in terms of the current price. Consumers' surplus can then be shown to be not only a function of the initial price, P_o, and the current price, P_t, but also a weighted history of prices. Consumers' surplus thus depends not only on the starting and finishing points, but on how the market got from one to the other. We begin by deriving surplus in the simplest case of a one period change in price.

The consumers' surplus change after one period can be obtained directly by integrating the linear lagged adjustment demand equation and subtracting the change in expenditures due to the change in price from P_o to P_1.

$$\begin{aligned} CS &= \int_{P_o}^{P_1} A_1 + Bp + cQ_o dp - (A_1 + BP_1 + cQ_o)(P_1 - P_o) \\ &= -\frac{1}{2}BP_1^2 - \frac{1}{2}BP_o^2 + BP_1P_o = -\frac{B}{2}(P_1 - P_o)^2 \end{aligned} \qquad \text{(A.2)}$$

This is precisely the area of the triangle under the demand curve from P_o to P_1, as shown in Figure 4, above.
Equation (A.2) indicates that the consumers' surplus loss equals the triangular area under the demand curve (at time t=1) above Q_1 and between P_o and P_1. Of course, this is just the usual result for a static demand curve. But how does the formula change for an arbitrary series of price changes of any given length?

To obtain an expression for the consumers' surplus change for a series of price changes between t=0 and an arbitrary time t in the future, one must once again integrate under the dynamic demand function. Writing the same expression as in equation (A.2) and then expanding lagged terms backward to P_o, gives an expression in terms of the full series of lagged prices, a full set of time-dependent constant terms, and the initial demand at Q_o. The expanded expression immediately raises the question of which price is to be integrated over, since it does not make sense to consider each price as a separate variable and perform t multiple integrations.

$$\begin{aligned} CS &= \int_{P_o}^{P_t} (A_t + BP + cQ_{t-1})dP - (P_t - P_o)Q_t(P_t) \\ &= \int_{P_o}^{P_t} \left(\sum_{i=0}^{t-1} c^i A_{t-i} + BP \sum_{i=0}^{t-1} c^i k_{t-1} + c^t Q_o \right) dp - \\ & (P_t - P_o)\left[\sum_{i=0}^{t-1} c^i A_{t-i} + BP \sum_{i=0}^{t-1} c^i k_{t-i} + c^t Q_o \right] \end{aligned} \tag{A.3}$$

Suppose each price at time t-i, i-0 to t-1, is represented parametrically by the following linear equation.

$$\begin{aligned} P_{t-i} &= P_o + (P_{t-i} - P_o)x = a + b_{t-i}x \\ dP_t &= (P_t - P_o)dx = b_t dx \end{aligned} \tag{A.4}$$

As the parametric variable x goes from 0 6 1, P_{t-i} goes from P_o 6 P_{t-i}. By substituting equation (A.4) into equation (A.3), one is now able to integrate over x, which will be equivalent to integrating over P from P_o to precisely each P_{t-i}.

Now we can rewrite equation (A.3), making the parametric substitution shown in equation (A.4) and integrating over x.

$$CS = \int_{P_o}^{P_t} (A_t + BP + cQ_{t-1})dP - (P_t - P_o)Q_t(P_t)$$

$$= \int_0^1 \left[\sum_{i=0}^{t-1} c^i A_{t-i} + B \sum_{i=0}^{t-1} c^i (a + b_{t-1} x) + c^t Q_o \right] b_t dx \quad - \qquad \text{(A.5)}$$

$$(P_t - P_o) \quad \left[\sum_{i=0}^{t-1} c^i A_{t-i} + B \sum_{i=0}^{t-1} c^i (a + b_{t-i} x) + c^t Q_o \right]$$

Since the integral of a sum equals the sum of the integrals of each term, it is convenient to treat each of the three summation terms of the integral in equation (A.5) individually. Consider the integral of the terms involving the period-specific constants, A.

$$\int_0^1 \sum_{i=0}^{t-1} c^i A_{t-i} b_t dx = \sum_{i=0}^{t-1} c^i A_{t-i} b_t x \Big|_0^1 = (P_t - P_o) \sum_{i=0}^{t-1} c^i A_{t-i} \qquad \text{(A.6)}$$

From equation (A.6) one can see that the first term of the integral in equation (A.5) will cancel the first term of the expenditures rectangle, in square brackets after the minus sign in equation (A.5). Likewise, it can be shown that the two terms involving $c^t Q_o$ will also cancel, leaving only the terms involving the price slope, B. Integrating that term produces terms involving both x and x^2.

$$\int_0^1 \sum_{i=0}^{t-1} Bc^i (a + b_{t-i} x) b_t dx = Bb_t \sum_{i=0}^{t-1} c^i (ax + \frac{1}{2} b_{t-i} x^2) \Big|_0^1$$
$$= B \sum_{i=0}^{t-1} c^i (P_o + \frac{1}{2}\{P_{t-i} - P_o\})(P_t - P_o) \qquad \text{(A.7)}$$

Because the other terms cancel, consumers' surplus is equal to the resulting term from equation (A.7) minus the corresponding expenditure term from equation (A.5) involving B.

$$CS = B \sum_{i=0}^{t-1} c^i \frac{1}{2} (P_t P_o - P_o^2 + P_t P_{t-i} - P_t P_o) \quad - \quad B \sum_{i=0}^{t-1} c^i P_{t-i} (P_t - P_o)$$
$$= -\frac{1}{2} B \sum_{i=o}^{t-1} c^i (P_o^2 - P_{t-i} P_o + P_t P_{t-i} - P_t P_o) \qquad \text{(A.8)}$$

This equation has some similarities to equation (A.2), consumers' surplus for a one-time price increase, but is a more complex weighted sum of the current price, all past prices, and the initial price. Since the intention is to estimate the consumers' surplus loss from monopolistic pricing of oil, the initial price level is replaced by the assumed competitive price. Fortunately, that is also almost exactly the price that prevailed for many years prior to the first oil price shock in 1973-74. Note that if the price of oil increased suddenly to P_t in year 1 and remained there, then all the $P_{t-i} = P_t$. In that case, equation (A.8) simplifies to the following.

$$CS = -\frac{1}{2}B\sum_{i=0}^{t-1}c^i(P_o^2 - P_tP_o + P_t^2 - P_tP_o) = -\frac{1}{2}B(P_t - P_o)^2\sum_{i=0}^{t-1}c^i \qquad \text{(A.9)}$$

If the price remained at P_t indefinitely (t 6 4), then equation (A.9) would further simplify since the infinite sum of the c^i would become 1/(1-c). The result for this special case was shown by Dargay and Goodwin (1995, p. 183). Since B/(1-c) is exactly the long-run price slope of the dynamic demand equation, equation (A.9) collapses to the same formula as the one period price change, shown in equation (A.2), except that instead of using the short-run price slope, B, one uses the long-run price slope, B/(1-c). This is an intuitively satisfying result, in that it says that a single, indefinite long-run price change can be computed by the consumers' surplus triangle under the long-run demand curve.

The derivation of producers' surplus change for a dynamic supply curve is precisely analogous, as can be readily seen from the exactly analogous form of the dynamic supply equation.

$$q_t = a_t + bP_t + gq_{t-1} \qquad \text{(A.10)}$$

In equation (A.10), quantity supplied is represented by lower case q, and parameters are represented by lower case Greek letters, but the structure of the equation is the same. The only difference in the result will be that the minus sign is missing, since the integration goes in the opposite direction.

This derivation provides a means of estimating consumers' and producers' surplus changes in the face of changing market prices and dynamically adjusting supply and demand. Added together, the surplus losses provide a lower bound on the total loss of potential GDP due to non-competitive pricing of oil.

APPENDIX B

DATA SOURCES

APPENDIX B: Data Sources

***OPEC and WORLD Oil Production**: 1970-98:* *International Petroleum Monthly, Nov 1999, Table 4.4: "World Oil Supply, 1970 – 1998," (**http://www.eia.doe.gov/emeu/ipsr/t44.txt**) **1999**: Short-Term Energy Outlook, Feb. 2000, Table A3: "Annual International Petroleum Supply and Demand Balance," (http://www.eia.doe.gov/pub/pdf/multi.fuel/02020002.pdf).*

***US Oil Demand: 1970-73**: **1970-97**: Annual Energy Review 1998, Table 5.1: "Petroleum Overview, 1949-1998," (**http://www.eia.doe.gov/pub/pdf/multi.fuel/038498_5.pdf);** **1998-99**: Short-Term Energy Outlook, Jan. 2000, Table A3: "Annual International Petroleum Supply and Demand Balance," (http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/jan00.pdf).*

***Net Imports: 1970-97**: Annual Energy Review (AER) 1998, Table 5.7: "Petroleum Net Imports by Country of Origin, 1960-1998," (**http://www.eia.doe.gov/pub/pdf/multi.fuel/038498_5.pdf);** **1998-99:** Short-Term Energy Outlook, Jan. 2000, Table A5: "Annual U.S. Petroleum Supply and Demand," (http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/jan00.pdf).*

***Imports from OPEC: 1970-72**: AER 1998, Table 5.7: "Petroleum Net Imports by Country of Origin, 1960-1998," (**http://www.eia.doe.gov/pub/pdf/multi.fuel/038498_5.pdf**); **1973-99**: Monthly Energy Review, Table 3.3d: "Petroleum Imports from Nigeria, Venezuela, Total Other OPEC, and Total OPEC," (http://www.eia.doe.gov/pub/energy.overview/monthly.energy/mer3-3d).*

***Refiner Acquisition Costs: 1970-97**: AER 1997, Table 5.19; "Crude Oil Refiner Acquisition Costs, 1968-1998," (http://www.eia.doe.gov/pub/pdf/multi.fuel/038498_5.pdf); **1998-99**: Short-Term Energy Outlook, Jan. 2000, Table A1: "Annual U.S. Energy Supply and Demand," (http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/jan00.pdf).*

***GDP Implicit Price Deflators**: **1970-98**: US Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, April 1999, National Data: D-2 Selected NIPA Tables, Table 7.1 (**http://www.bea.doc.gov/bea/pubs.htm**); **1999**: Short-Term Energy Outlook, Jan. 2000, Table 1: "U.S. Macroeconomic and Weather Assumptions," (http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/jan00.pdf).*

***Discount Rate**: Federal Reserve Bank of Minneapolis, Discount rates -- historic through present (**http://woodrow.mpls.frb.fed.us/economy/bankdir/disc.html)**.*

***Gross Domestic Product (GDP): 1970-98**: US Department of Commerce, Bureau of Economic Analysis, Survey of Current Business, August 97, Table 2A, (**www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPA/1999/0399dpgc.pdf**); **1999:** Short-Term Energy Outlook, Jan. 2000, Table A1: "Annual U.S. Energy Supply and Demand," (http://www.eia.doe.gov/pub/forecasting/steo/oldsteos/jan00.pdf).*

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