

Costs of Oil Dependence: A 2000 Update

David L. Greene

Center for Transportation Analysis
Oak Ridge National Laboratory
National Transportation Research Center
2360 Cherahala Boulevard
Knoxville, TN 37932
Phone: (865) 946-1310
Fax: (865) 946-1314
Email: dlgreene@ornl.gov

Nataliya I. Tishchishyna

University of Tennessee
Knoxville, TN 37916

December 2000

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
UT-BATTELLE, LLC
for the
U. S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

The submitted manuscript has been authored by a contractor of the U.S. government under contract DE-AC05-00OR22725. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iii
ACKNOWLEDGMENTS	iv
ABSTRACT	v
1. WHAT IS OIL DEPENDENCE?	1
2. OIL DEPENDENCE, PAST AND PRESENT	3
3. COMPONENTS OF THE COSTS OF OIL DEPENDENCE	8
3.1 LOSS OF POTENTIAL GDP	9
3.2 MACROECONOMIC ADJUSTMENT COSTS	9
3.3 TRANSFER OF WEALTH	10
4. MEASURING THE COSTS	10
4.1 TRANSFER OF WEALTH	11
4.2 LOSS OF POTENTIAL GDP	13
4.3 MACROECONOMIC ADJUSTMENT LOSSES	15
5. DATA	17
5.1 ESTIMATES OF PRICE SLOPES AND ADJUSTMENT RATES OF OIL SUPPLY AND DEMAND IN THE UNITED STATES	18
6. RESULTS	22
6.1 SENSITIVITY ANALYSIS	27
7. CONCLUSIONS	31
8. REFERENCES	33

LIST OF FIGURES

Figure 1. Oil Price and Economic Growth, 1970–98	2
Figure 2. U.S. Petroleum Consumption by Sector	5
Figure 3. U.S. Refiners' Acquisition Cost for Imported Oil, 1970–1999	6
Figure 4. World Oil Market Shares, 1998	7
Figure 5. Diagram Showing Wealth Transfer and Potential GDP Losses	12
Figure 6. U.S. Oil Imports and Oil Production, 1970–1999	12
Figure 7. Oil Cost Share of GDP, 1970–1999	21
Figure 8. Oil Dependence Costs to U.S. Economy, 1970–2000	25

LIST OF TABLES

Table 1. Short-Run Elasticities of U.S. Petroleum Supply and Demand at Various Prices	19
Table 2. Estimates of the Price Elasticity of GDP with Respect to the Price of Crude Oil	20
Table 3. Base Case Estimates of Oil Dependence Costs	24
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)	28

ACKNOWLEDGMENTS

This research was carried out with support from the U.S. Department of Energy. The opinions and conclusions expressed, however, are the sole responsibility of the authors.

ABSTRACT

Oil dependence remains a potentially serious economic and strategic problem for the United States. Recently, world oil prices leapt from \$10 per barrel in January of 1999 to \$30 per barrel in the summer of 2000, as a direct consequence of supply restraints by the OPEC cartel. Estimates of the total economic costs to the United States of such oil market upheavals during 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. Transportation is at the center of the oil dependence issue. More than 25 years after the first world oil crisis in 1973-74, the U.S. transportation system comprises 67% of U.S. petroleum demand (25% of world oil demand) and relies on oil for more than 95% of its energy needs.

1. WHAT IS OIL DEPENDENCE?

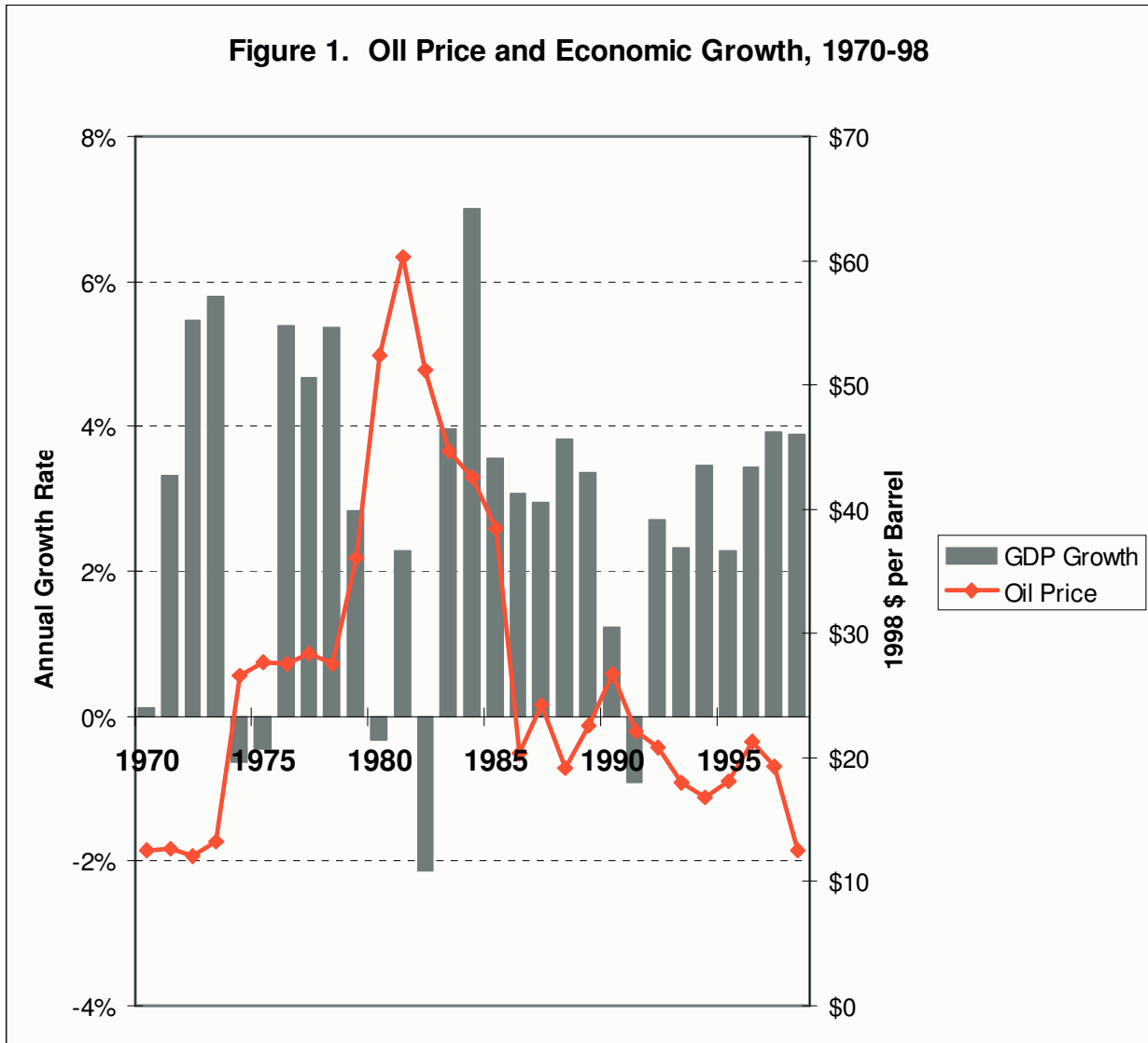
When the price of oil fell to \$10 per barrel in the winter of 1998-99 the OPEC cartel seemed to be powerless, and it was reasonable to ask whether oil dependence was still an important issue for the United States. The American public continued to believe that it was. A 1998 poll found that over 80% 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.

Major oil price shocks have disrupted world energy markets four times in the last thirty years (1973-74, 1979-80, 1990-91). Each of the first three shocks was followed by an economic recession in the United States (Figure 1). While few economists expect last year's price shock to cause a recession, it has undoubtedly slowed the economy's growth. Prices in the vicinity of \$30 per barrel appear to have reduced U.S. GDP by roughly 2% (about \$150 billion).

This paper attempts to put the problem of oil dependence in perspective by estimating its costs to the U.S. economy over the past thirty years. Estimating these costs requires an economically precise answer to the following question. What is "oil dependence"?

Oil dependence is most 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 cause oil prices to jump, the U.S. economy is generally better off paying the higher prices for imports than attempting to rely solely on domestic sources of supply (U.S. GAO, 1996). Oil dependence is more rigorously defined as the product of four key factors: (1) a non-competitive world oil market strongly influenced by the OPEC cartel, (2) high levels of U.S. oil imports, (3) oil's critical

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



role in the U.S. economy, and (4) the absence of economical and readily available substitutes for oil. Transportation plays the central role in this problem because transportation vehicles account for 67% of U.S. oil consumption (and nearly all of the high-value light products that drive petroleum markets) and transportation remains more than 95% dependent on oil for energy. Nearly all of the non-petroleum energy used for transportation is electricity or natural gas to power pipelines, or blending additives to gasoline such as ethanol or MTBE (Davis, 2000).

Counting the costs of oil dependence would be an academic exercise if there were nothing we could do about it. Fortunately, there is. Solving the oil dependence problem will require developing advanced technologies to increase the efficiency of energy use in transportation, lowering the costs of alternative energy sources for transportation, and improving the technology of oil exploration and recovery. Increasing the ability of energy markets to respond to oil price increases will undermine cartel market power in world oil markets and significantly reduce the future costs of oil dependence (Schock et al., 1999).

2. OIL DEPENDENCE, PAST AND PRESENT

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 more major 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 declined 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.

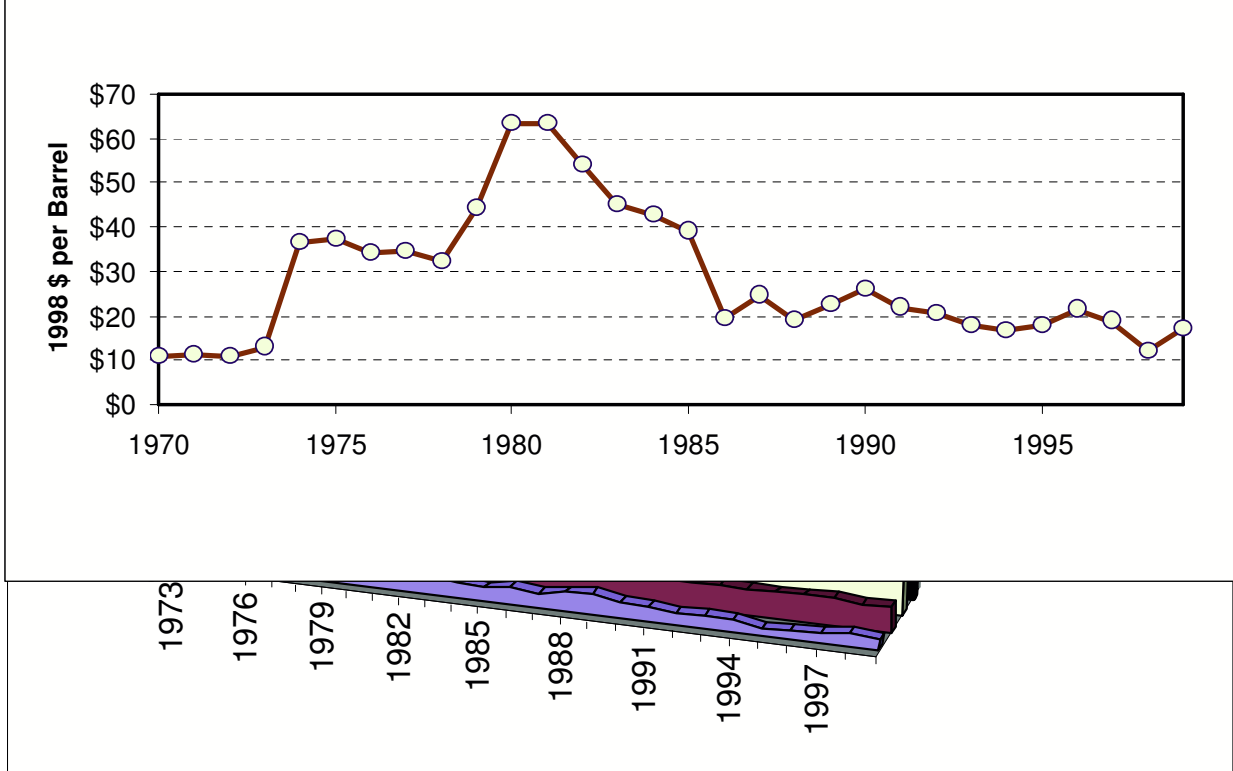
U.S. net imports of oil reached their highest recorded level in 1998, 51.6% of U.S. petroleum supply. With higher oil prices in 1999, import dependence decreased slightly to 50.8% of total U.S. oil requirements (U.S. DOE/EIA, 2000b, table 1.8). With net imports averaging 9.6 mmbd, and the average price 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 increases 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 (Figure 2). 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.

Figure 3. U.S. Refiners' Acquisition Cost for Imported Oil, 1970 - 1999



The oil price collapse of 1986 was followed by more than a decade of lower oil prices, convincing many that OPEC's days as a dominant force in world oil markets were over (Figure 3). 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).

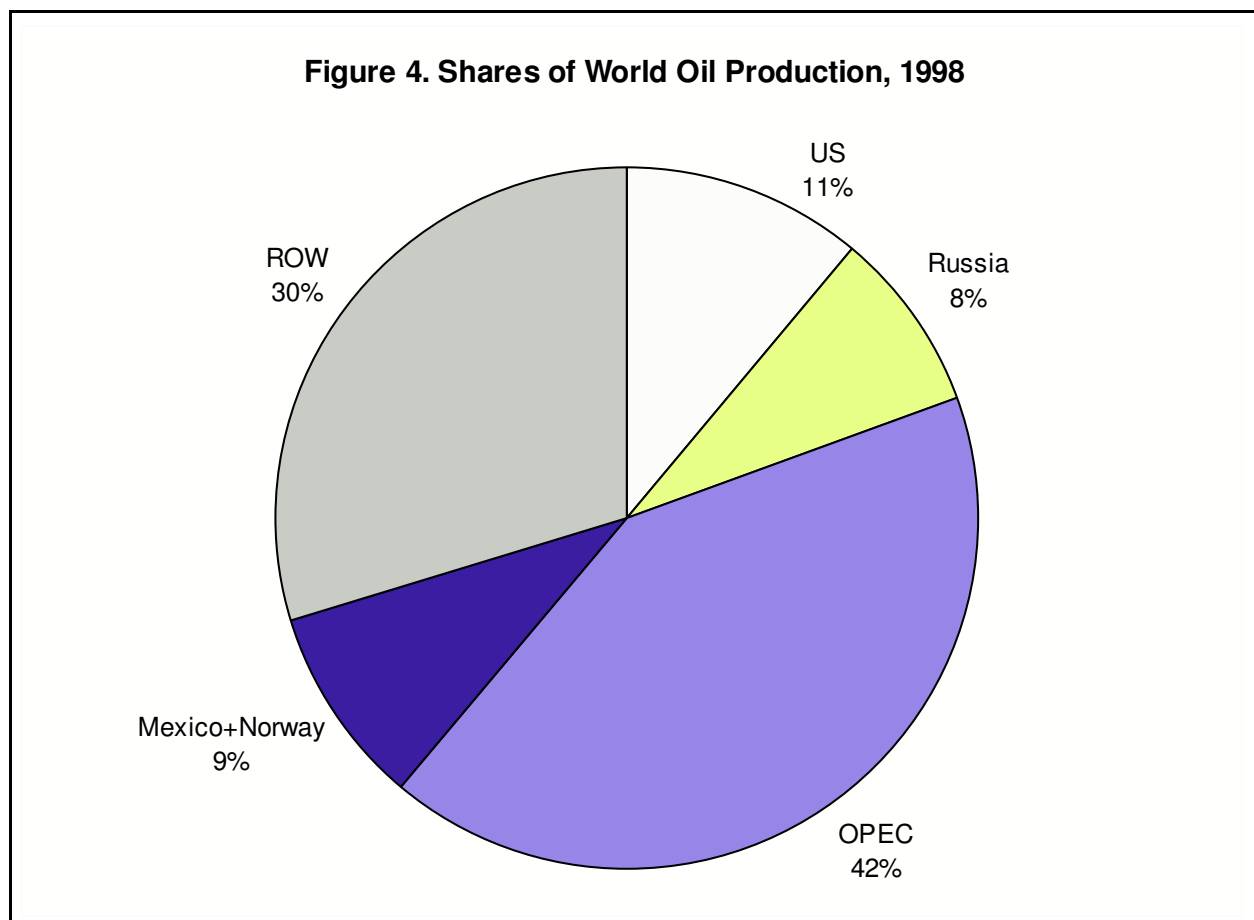
But as 1999 unfolded, the consensus view of an ineffectual OPEC and a future of abundant, cheap oil has been overturned by a steady rise of oil prices to \$24 per barrel in January 2000. Not only was the more than doubling of oil prices largely unexpected, but it was brought about by effective action 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)

Or it could reformulate itself yet again, possibly adding fossil fuel rich states of the former Soviet Union (Figure 4). 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, sooner or later 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. OPEC’s market power is a direct result of its share of the world’s oil market, the lack of ready and efficient substitutes for oil, and the inability of other

world oil producers to respond quickly and effectively to higher oil prices. 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 hydrocarbon 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)



3. COMPONENTS OF THE COSTS OF OIL DEPENDENCE

When monopoly power is used to raise prices above competitive market levels, oil consuming economies incur three types 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 (Greene and Leiby, 1993). There are also important military, political, and environmental consequences of oil dependence, but these issues are beyond the scope of this paper (see, e.g., Delucchi and Murphy, 1996; Hall 1992).

3.1 LOSS OF POTENTIAL GDP

Any increase in the price of oil signals the economy that a fundamental resource has become more scarce. As a result, the economy can produce somewhat less with the same endowment of capital, labor, materials, and other energy resources. This shrinkage of productive capability is called the *loss of potential GDP*, emphasizing that even if all resources were fully employed in their best uses, the potential to produce is reduced because (economically) oil is more scarce. The loss of potential GDP persists as long as oil prices remain elevated.

3.2 MACROECONOMIC ADJUSTMENT COSTS

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 (already diminished) 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.

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. Recent research has shown that oil price shocks cause greater job destruction than creation, and that the most energy-intensive sectors suffer the most (Davis and Haltiwanger, 1997). Oil price shocks necessitate labor reallocation that leads to a temporary increase in unemployment, persisting for perhaps 4 years (Lougani, 1986).

3.3 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. 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 gained by producing nations. It is, however, a real economic loss to the United States as a consuming nation.

4. MEASURING THE COSTS

Few economists would argue with the claim that 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. But compared to what? Estimating the historical costs of oil dependence requires a counterfactual case to compare to. What would world oil markets have been like if oil producers had not formed OPEC and exercised monopoly power? The alternative against which the three types of costs are calculated is a competitive world oil market, with stable oil prices such as prevailed prior to the first oil price shock in 1973.

4.1 TRANSFER OF WEALTH

The transfer of wealth can be measured as the increase in price above competitive market levels multiplied by the total volume of U.S. (Net) imports. This is illustrated in Figure 5. U.S. oil supply is insufficient to supply U.S. demand at the initial competitive world oil price, P_0 . U.S. supply is $^S Q_0$, demand is $^D Q_0$, so $(^D Q_0 - ^S Q_0)$ 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 6.

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. Three different indicators 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 \$.

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 3). Simulations of competitive market conditions have produced a variety of price estimates in the general vicinity of \$10 per barrel. Greene et al.

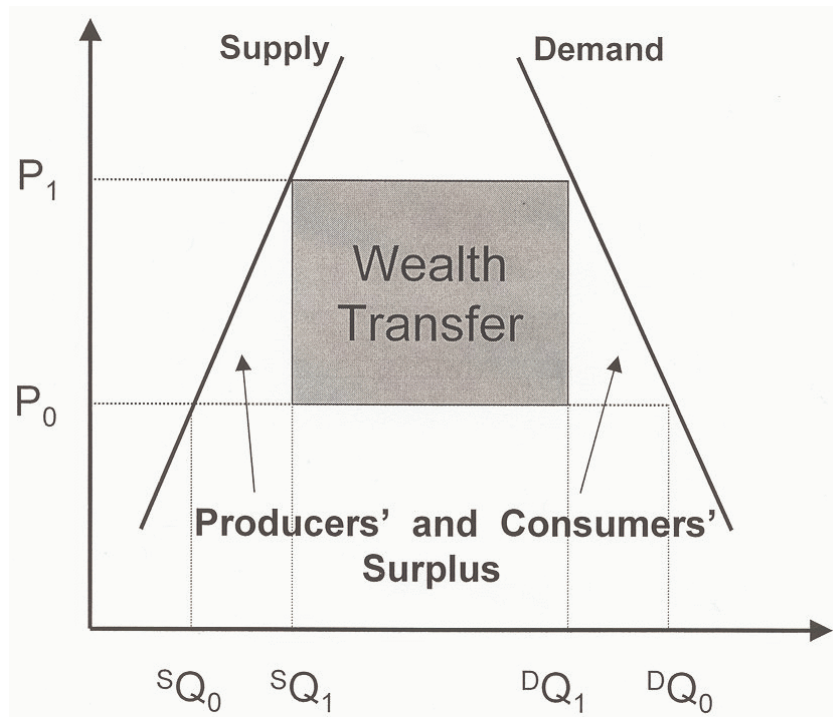
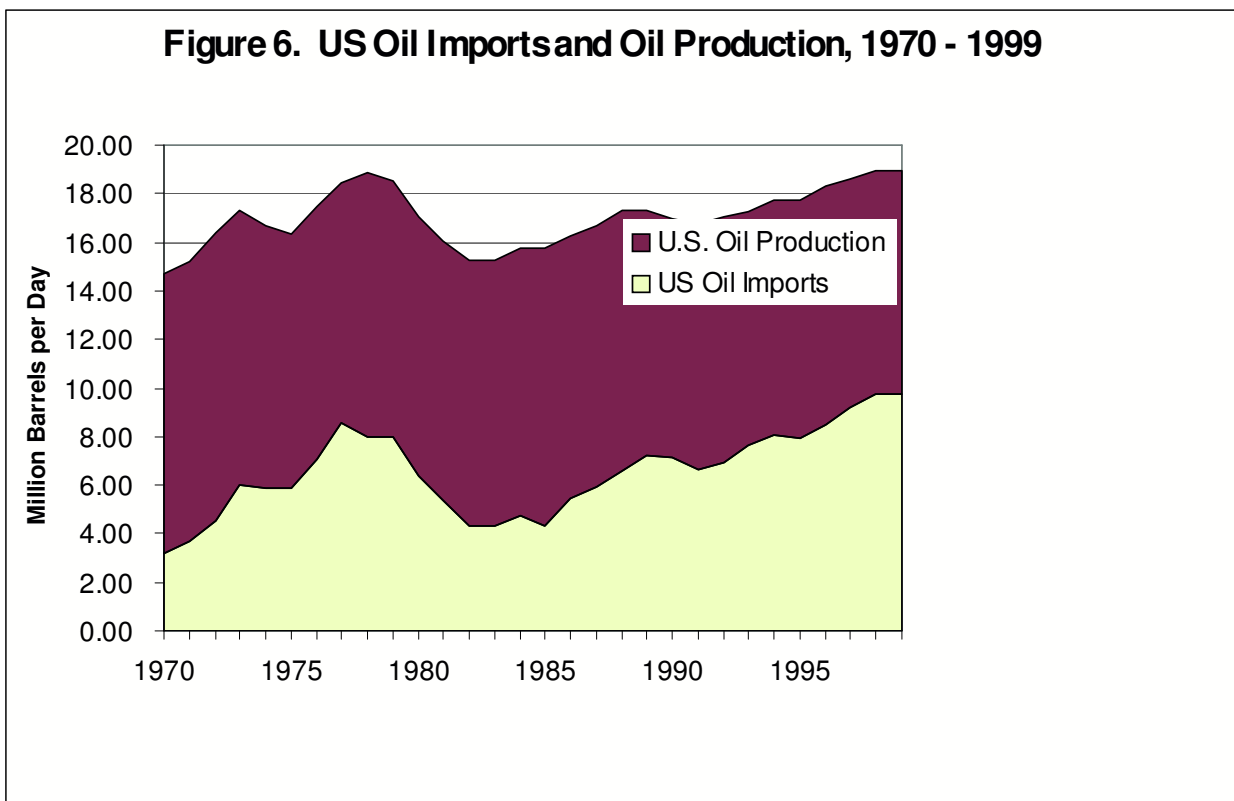


Figure 5. Diagram showing Wealth Transfer and Potential GDP Losses

(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 .



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

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

4.2 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 oil expenditures is an upper bound on the permanent income loss (Eastwood, 1992, pp. 403-404).

Measuring deadweight losses of consumers’ and producers’ surplus is a 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 5. 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.

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. The method for accurately estimating dynamic losses is explained in Greene and Tishchishnya (2000). 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.

4.3 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 through 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, 1987). 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%.

The estimation of macroeconomic adjustment costs relies on four key parameters: (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) the rate of adjustment of the economy to sudden price changes.

The median elasticity estimate from Hickman's (1987) study of -0.046 is assumed to apply in 1982. However, 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. After the first year, the economy is assumed to adjust to the price shock at a rate that reduces the macro-economic adjustment costs by 25% each year.

5. 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 Greene and

Tishchishyna, 2000, 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, 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.

5.1 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 of 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		Supply	
	MMBD	Elasticity	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

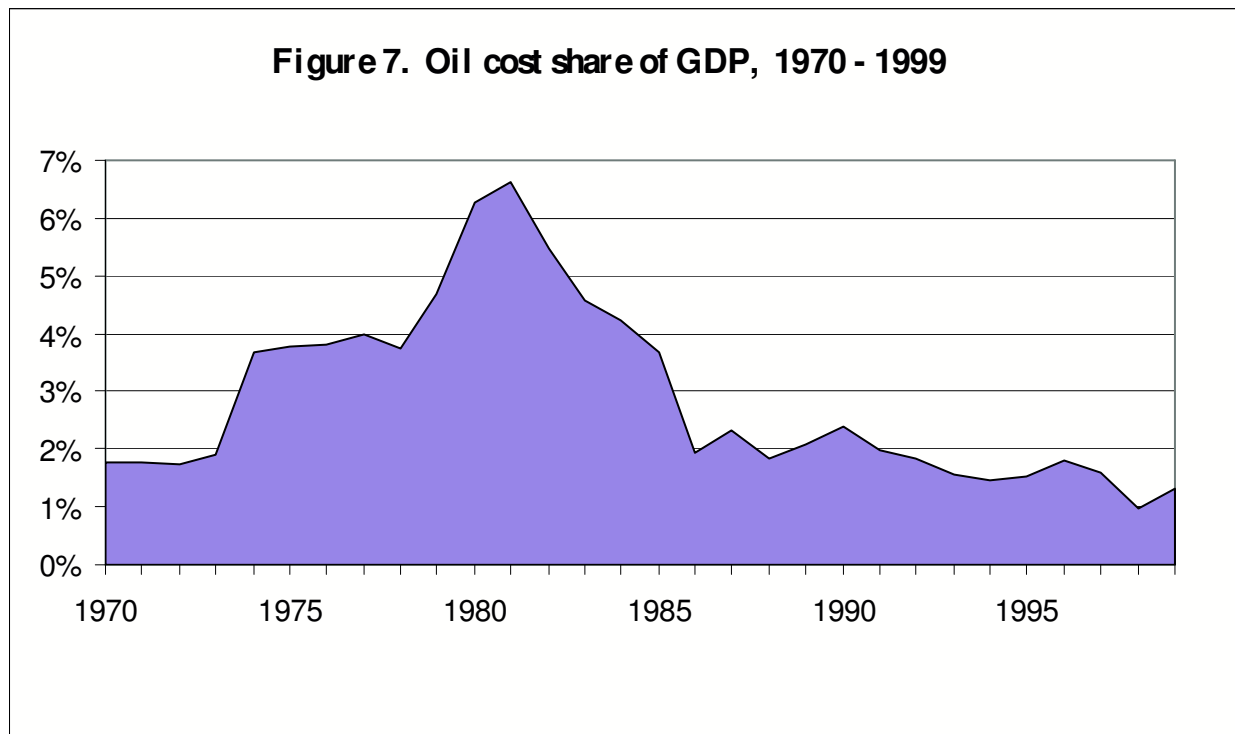
The sensitivity of GDP to changes in the price of oil is the most critical parameter in this analysis. It is convenient to summarize this relationship in terms of the elasticity of GDP with respect to the price of oil, a dimension-less coefficient equal to the percent change in GDP for a 1% change in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

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 (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 (2000a)		-0.01

The estimates of GDP elasticity with respect to oil price presented in Table 2 appear related to 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 7). 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 significantly increased. If oil substitutability is lower in these two sectors than in the utility and residential/commercial buildings sector, then the overall substitutability of oil in the economy may have decreased (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 (2000a) estimated that the 1998–99 doubling of world oil prices from \$11 to \$22 per barrel would produce a -0.50% change in GDP in 1999 and a -1.00% change in 2000. The difference is due to 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.

6. 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, despite the fact that 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 \$1.20 trillion, or 35%. Wealth transfer is the second largest component at \$1.16 trillion (34%). Macroeconomic adjustment losses are estimated to come in third, at \$1.06 trillion (31%). 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.

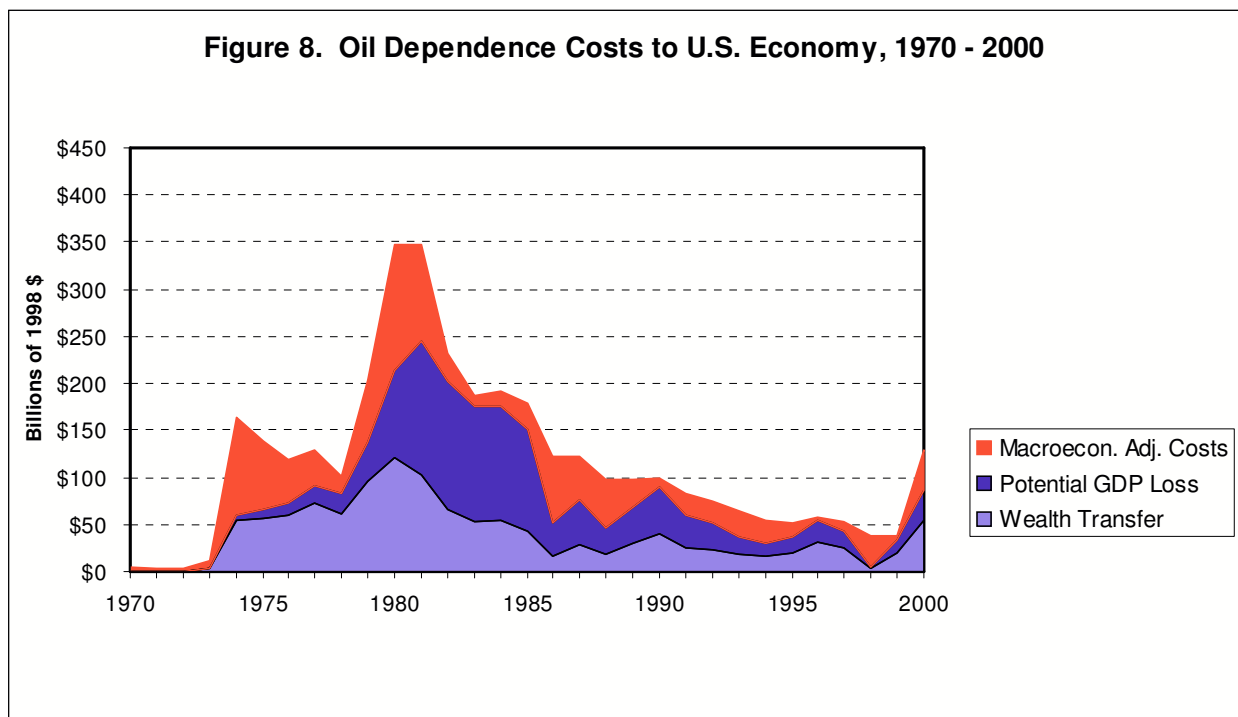
The greatest economic damage was done during the first half of the 1980s, a period in which oil prices surged to a peak of over \$60 per barrel in 1981 (1998 \$). In the estimates presented here (Table 3, Figure 8) the oil crisis of 1973-74 appears to have had a much smaller economic impact, although 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 United States. 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	Competitive Price 1998 \$	Potential GDP Loss	Macro-Econ Adj. Loss	Wealth Transfer	Total Economy Loss	U. S. GDP	U. S. Oil Consumpt	U. S. Oil Imports
	1998 \$		Bill \$ 1998	Bill \$ 1998	Bill \$ 1998		1998 \$	(Millions of Barrels per Day)	
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									



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. Potential 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. 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 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 average \$26/barrel in 2000, as appears likely, all three types of losses will increase in 2000 adding up to a total loss of about \$128 billion. The estimated economic impact would amount to roughly a 1% decrease in the rate of GDP growth in 2000.

6.1 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).

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

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

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.

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 7 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.

7. CONCLUSIONS

Even over a period as long as thirty years, economic costs on the order of \$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, and total net interest payments by the federal government were of the same general magnitude (U.S. Census Bureau, 1999, table 543). The present value of these past losses amounts to 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. While a recession early in 2001 appears unlikely at the time of writing, it is already clear that economic growth has slowed significantly. 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 declined, 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 1-2% 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 United States must reduce it's oil consumption and increase its supplies, but it must also 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 (Greene, 1999).

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.

8. REFERENCES

Anderson, R.N. (1998). "Oil Production in the 21st Century," *Scientific American*, vol. 278, no. 3, pp. 86–91.

- Berg, E., S. Kverndokk and K.E. Rosendahl. (1997). "Market Power, International CO₂ Taxation and Oil Wealth," *The Energy Journal*, vol. 18, no. 4, pp. 33–72.
- Darby, M.R. (1982). "The Price of Oil and World Inflation and Recession," *American Economic Review*, vol. 72, pp. 01738–751.
- Dargay, J. and D. Gately. (1994). "Oil Demand in the Industrialized Countries," *The Energy Journal*, vol. 15, special issue, pp. 39–67.
- Davis, Stacy C. (2000). *Transportation Energy Data Book: Edition 20*, ORNL-6959, Oak Ridge National Laboratory, Oak Ridge, TN, December.
- Davis, S.J. and J. Haltiwanger. (1997). "Sectoral Job Creation and Destruction Responses to Oil Price Changes and Other Shocks," presented at the conference on *International Energy Security: Economic Vulnerability to Oil Price Shocks*, Washington, DC, October 3–4, 1996, sponsored by the U.S. Department of Energy and Department of State.
- Delucchi, M.A. and J. Murphy. (1996). *U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles*, UCD-ITS-RR-96-3(15), Institute of Transportation Studies, University of California, Davis, CA.
- Eastwood, R.K. (1992). "Macroeconomic Impacts of Energy Shocks," *Oxford Economic Papers*, vol. 44, pp. 403–425.
- Gallagher, P. and D. Johnson. (1999). "Some New Ethanol Technology: Cost Competition and Adoption Effects in the Petroleum Market," *The Energy Journal*, vol. 20, no. 2, pp. 89–120.
- Gately, D. (1995). "Strategies for OPEC's Pricing and Output Decisions," *The Energy Journal*, vol. 16, no. 3, pp. 1–38.

- Gately, D. and P. Rappoport. (1988). "The Adjustment of U.S. Oil Demand to the Price Increases of the 1970s," *The Energy Journal*, vol. 9 no. 3, pp. 93–107.
- Gisser, M. and T.H. Goodwin. (1986). "Crude Oil and the Macroeconomy: Tests of Some Popular Notions," *Journal of Money, Credit, and Banking*, vol. 18, pp. 95–103.
- Greene, D.L. (1999). *An Assessment of Energy and Environmental Issues Related to the Use of Gas-to-Liquid Fuels in Transportation*, ORNL/TM-1999/258, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November.
- Greene, D.L. (1997). "Oil Dependence: The Value of R&D," Proceedings of the 32nd *Intersociety Energy Conversion Engineering Conference*, vol. 3, pp. 2148–2153, American Institute of Chemical Engineers, New York.
- Greene, D.L. and P. N. Leiby. (1993). *The Social Costs to the U.S. of Monopolization of the World Oil Market, 1972-1991*, ORNL-6744, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March.
- Greene, D.L. and N.I. Tishchishyna. (2000). *Costs of Oil Dependence: A 2000 Update*, ORNL/TM-2000/152, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May.
- Greene, D.L., D.W. Jones and P.N. Leiby. (1998). "The Outlook for U.S. Oil Dependence," *Energy Policy*, vol. 26, no. 1, pp. 55–69.
- Greene, D.L., D.W. Jones and P.N. Leiby. (1995). *The Outlook for U.S. Oil Dependence*, ORNL-6873, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May.
- Hall, D.C. (1992). "Oil and National Security," *Energy Policy*, vol. 20, pp. 1089-1096.
- Hamilton, J.D. (1996). "Analysis of the Transmission of Oil Price Shocks Through the Economy," presented at the *symposium on International Energy Security: Economic Vulnerability to Oil Price Shocks*, Washington, DC, October 3-4, 1996.

- Hamilton, J.D. (1983). "Oil and the Macroeconomy Since World War II," *Journal of Political Economy*, vol. 91, pp. 228–248.
- Heilke, W.L. (1991). "The Impact of an Oil Market Disruption on the Price of Oil: A Sensitivity Analysis," *The Energy Journal*, vol. 12, no. 4, pp. 105–116.
- Hickman, B.G. (1987). "Macroeconomic Impacts of Energy Shocks and Policy Responses: A Structural Comparison of Fourteen Models," *Macroeconomic Impacts of Energy Shocks*, Hickman, Huntington and Sweeney, eds., Elsevier Science Publishers B.V., North Holland.
- Hooker, M.A. (1996). "Exploring the Robustness of the Oil Price-Macroeconomy Relationship: Empirical Specifications and the Role of Monetary Policy," presented at the *Symposium on International Energy Security: Economic Vulnerability to Oil Price Shocks*, Washington, DC, October 3-4, 1996.
- Huntington, H.G. (1996). "Estimating Macroeconomic Impacts of Oil Price Shocks with Large-Scale Econometric Models: EMF-7 and Recent Trends," presented at the *symposium on International Energy Security: Economic Vulnerability to Oil Price Shocks*, Washington, DC, October 3–4, 1996.
- Huntington, H.G. (1994). "Oil Price Forecasting in the 1980s: What Went Wrong?" *The Energy Journal*, vol. 15, no. 2, pp. 1–22.
- Huntington, H.G. (1993). "OECD Oil Demand," *Energy Economics*, vol. 15, no. 1, pp. 49–56.
- Huntington, H.G. (1991). "Inferred Demand and Supply Elasticities from a Comparison of World Oil Models," EMF WP 11.5, The Energy Modeling Forum, Stanford University, Stanford, California, January.

- Lee, K., S. Ni and R.A. Ratti. (1995). "Oil Shocks and the Macroeconomy: The Role of Price Variability," *The Energy Journal*, Vol. 16, no. 4, pp. 39–56.
- Loungani, P. (1986). "Oil Price Shocks and the Dispersion Hypothesis," *The Review of Economics and Statistics*, pp. 536–539.
- Mork, K.A. (1989). "Oil and the Macroeconomy When Prices Go Up and Down: An Extension of Hamilton's Results," *Journal of Political Economy*, vol. 97, no. 3, pp. 740–744.
- Mork, K.A. and R.E. Hall. (1980). "Energy Prices, Inflation, and Recession, 1974-1975," *The Energy Journal*, vol. 1, no. 3, pp. 31–63.
- Mork, K.A., O. Olsen and H.T. Mysen. (1994). "Macroeconomic Responses to Oil Price Increases and Decreases in Seven OECD Countries," *The Energy Journal*, vo. 15, no. 4, pp. 19–35.
- Mory, J.F. (1993). "Oil Prices and Economic Activity: Is the Relationship Symmetric?" *The Energy Journal*, vol. 14, no. 4, pp. 151–161.
- Pindyck, R.S. (1980). "Energy Price Increases and Macroeconomic Policy," *The Energy Journal*, vol. 1, no. 4, pp. 1–20.
- Porter, E.D. (1992). "U.S. Petroleum Supply: History, Prospects, and Policy Implications," Research Study #064, American Petroleum Institute, Washington, DC, September.
- Ram, R. and D.D. Ramsey. (1989). "Government Capital and Private Output in the United States: Additional Evidence," *Economic Letters*, vol. 30, pp. 223–226.
- Rasche, R.H. and J.A. Tatom. (1981). "Energy Price Shocks, Aggregate Supply and Monetary Policy: The Theory and the International Evidence," in K. Brunner and A.H. Melzer, eds., *Supply Shocks, Incentives and National Wealth*, Carnegie-Rochester Conference Series on Public Policy, vol. 14, pp. 9–93.

- Salupkas, A. (1999). "An Outsider Revives a Cartle," *New York Times*, October 24, ISSN 03624331.
- Santini, D.J. (1992). "The Petroleum Problem: The Increasing Need to Develop Alternative Transportation Fuels," *Energy Growth and the Environment: Advances in the Economics of Energy and Resources*, vol. 7, pp. 59–99.
- Schock, R.N., W. Fulkerson, M.L. Brown, R.L. San Martin, D.L. Greene and J. Edmonds. (1999). "How Much Is Energy R&D Worth as Insurance," *Annual Review of Energy and the Environment*, vol. 24, pp. 487–512, Annual Reviews, Palo Alto, California.
- Smyth, D.J. (1993). "Energy Prices and the Aggregate Production Function," *Energy Economics*, vol. 15, pp. 105–110.
- Suranovic, S.M. (1994). "Import Policy Effects on the Optimal Oil Price," *The Energy Journal*, vol. 15, no. 3, pp. 123–144.
- Sustainable Energy Coalition. (1998). "America Speaks Out on Foreign Oil Dependency," <http://www.ucsusa.org/energy/oil.poll.html> .October 21, 1998.
- U.S. Census Bureau. (1999). *Statistical Abstract of the United States: 1999*, U.S. Government Printing Office, Washington, DC.
- U.S. Department of Energy, Energy Information Administration. (2000a). "Oil Price Impacts on the U.S. Economy," presentation slides and notes posted at <ftp://ftp.eia.doe.gov/pub/pdf/feature/Econ1/sld001.htm> , February 21, 2000.
- U.S. Department of Energy, Energy Information Administration. (2000b). "Monthly Energy Review," DOE/EIA-0035(2000/11), Washington, DC, November.
- U.S. Department of Energy, Energy Information Administration. (1999). *Annual Energy Outlook 2000*, DOE/EIA-0383(2000), Washington, DC, December.

- U. S. Department of Energy, Interagency Working Group. (1990). *Strategic Petroleum Reserve: Analysis of Size Options*, DOE/IE-0016, table 1, p. 8-1, Washington, DC, February.
- U.S. General Accounting Office. (1996). *Energy Security: Evaluating U.S. Vulnerability to Oil Supply Disruptions and Options for Mitigating Their Effects*, GAO/RCED-97-6, Washington, DC, December.
- Watkins, G.C. (1992). "The Hotelling Principle: Autobahn or Cul de Sac?" *The Energy Journal*, vol. 13, no. 1, pp. 1–24.
- Yergin, D. (1992). *The Prize*, Simon and Schuster, New York.