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OIL DEPENDENCE: THE VALUE OF R&D

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ABSTRACT

Over the past quarter century the United States' dependence on oil has cost its economy on the order of $5 trillion. Oil dependence is defined as economically significant consumption of oil, given price inelastic demand in the short- and long-run and given the ability of the OPEC cartel to use market power to influence oil prices. Although oil prices have been lower and more stable over the past decade, OPEC still holds the majority of the world's conventional oil resources according to the best available estimates. OPEC's share of the world oil market is likely to grow significantly in the future, restoring much if not all of their former market power. Other than market share, the key determinants of OPEC's market power are the long- and short-run price elasticities of world oil demand and supply. These elasticities depend critically on the technologies of oil supply and demand, especially the technology of energy use in transportation. Research and development can change these elasticities in fundamental ways, and given the nature of the problem, the government has an important role to play in supporting such research.

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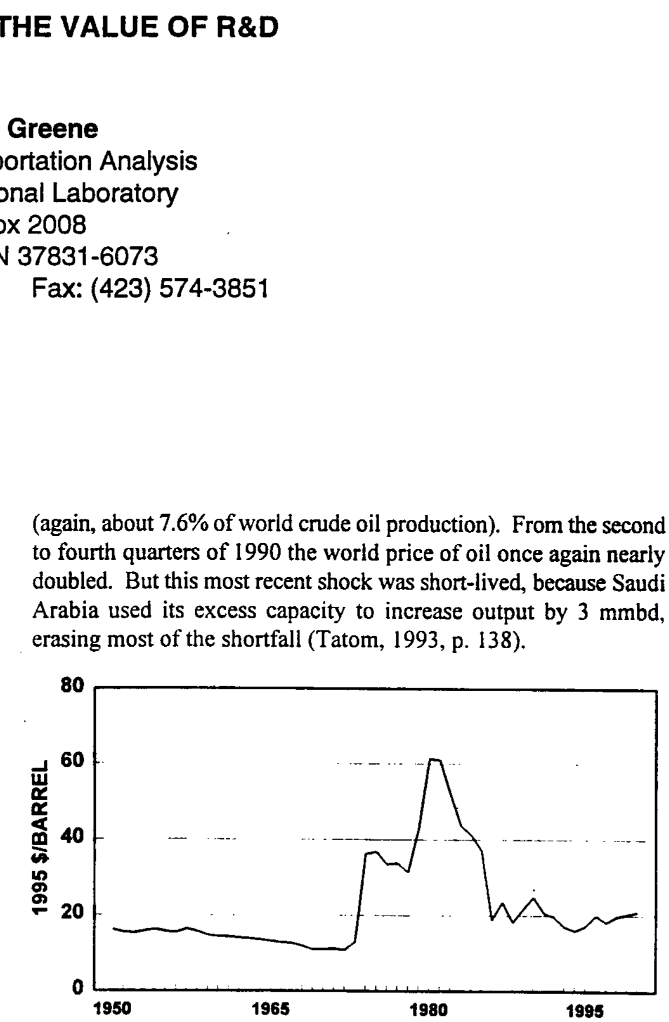
ABSTRACT

Over the past quarter century the United States' dependence on oil has cost its economy on the order of $5 trillion. Oil dependence is defined as economically significant consumption of oil, given price inelastic demand in the short- and long-run and given the ability of the OPEC cartel to use market power to influence oil prices. Although oil prices have been lower and more stable over the past decade, OPEC still holds the majority of the world's conventional oil resources according to the best available estimates. OPEC's share of the world oil market is likely to grow significantly in the future, restoring much if not all of their former market power. Other than market share, the key determinants of OPEC's market power are the long- and short-run price elasticities of world oil demand and supply. These elasticities depend critically on the technologies of oil supply and demand, especially the technology of energy use in transportation. Research and development can change these elasticities in fundamental ways, and given the nature of the problem, the government has an important role to play in supporting such research.

OIL DEPENDENCE: WHAT'S THE PROBLEM?

In October of 1973, the Arab states belonging to the Organization of Petroleum Exporting Countries (OPEC) announce an oil boycott of nations that supported Israel during the "October War." Decades of dependable and declining oil prices suddenly came to an end (Figure 1). With a 4.2 million barrels per day (mmbd) reduction in oil supply (about 7.5% of world output), the Arab OPEC states caused a doubling of world oil prices. In 1979-80 a loss of 5.4 mmbd of output from Iran and Iraq (about 9% of world production) again doubled the world price of oil. In both cases, OPEC members restricted output in succeeding years despite enormous, easily developable, low cost reserves, in order to maintain the higher prices. When Iraq invaded Kuwait in 1990, output from those two countries dropped by 4.8 mmbd between May and December (again, about 7.6% of world crude oil production). From the second to fourth quarters of 1990 the world price of oil once again nearly doubled. But this most recent shock was short-lived, because Saudi Arabia used its excess capacity to increase output by 3 mmbd, erasing most of the shortfall (Tatom, 1993, p. 138).



U.S. DOE/EIA, AER 1995, Tables 5.16 and 5.19.

FIGURE 1. CRUDE OIL PRICES, 1949-1995

At least one of the three price shocks of the past was the result of deliberate, collusive action by OPEC producers. The other two were caused by acts of war. Whatever the causes, the first two resulted in price increases sustained for several years because OPEC members deliberately and collusively decided not to increase their oil production. Such anticompetitive behavior constitutes a rather obvious market failure. It is a market failure that has cost oil consuming economies like the United States dearly over the past quarter century. The question, of course, is whether anything can be done about it. A more precise understanding of the nature of the oil dependence problem leads to the conclusion that something can indeed be done, and that changing the technologies of oil supply and of demand for oil in transportation may be the answer.

The key to understanding the oil dependence problem is understanding what determines the market power of a partial monopolist (a producer that controls a large share of the market but not all of it), because this is the position in which OPEC finds itself. A producer has market power when by restricting its output it can cause market prices to rise. For a partial monopolist, profit is maximized when price (P) is increased to a level determined by three parameters: (1) the price elasticity[1] of market demand ($\beta<0$), (2) the supply responsiveness of competing producers (measured as the number of barrels replaced by other suppliers when the partial monopolist cuts its output by one barrel ($-1 \leq \rho \leq 0$), and (3) the partial monopolist's market share ($0 \leq \sigma \leq 1$). The rest of world supply response depends directly on the price elasticity of oil supply. As can be seen in equation (1), the smaller the price elasticity of demand, the smaller the "rest of world" supply response, and the greater the monopolist's market share, the higher the profit maximizing price.

$$P = \frac{1}{1 + [(1/\beta)\ \sigma\ (1+\rho)]} \qquad (2)$$

In the case of OPEC, it is not a single producer but a cartel of nation states, and that greatly complicates matters. Before a significant action can be taken, a sufficient number of members must agree. Agreement is facilitated, however, by the fact that all members can reap substantial profits from an effective strategy of supply restriction.

An extremely important feature of world oil markets is the fact that price elasticities in the short run (say one year) are much smaller, about an order of magnitude smaller, than long-run price elasticities. This implies two things: (1) short-run profit maximizing prices are much higher than long-run profit maximizing prices, and (2) price levels that give the most profit in the short run cannot be sustained in the long run. A curve describing the cartel's maximum profit price as a function of its market share can be obtained by substituting price elasticities of supply and demand into equation (1). The two curves shown in Figure 2 were derived by substituting first short-run (upper curve) and then long-run estimates of oil supply and demand elasticities in equation (1). In theory, any point between the two curves is achievable by the cartel and, over some time period is profit maximizing. On the same graph, actual OPEC core (the small group of largest OPEC producers) market share and historical prices have been plotted. Note that OPEC cannot move vertically in this space, since price can only be increased by cutting output, and this means loss of market share. Also, the amount of market share that must be sacrificed to achieve a given increase in price depends on the rate of growth of world oil demand, as well as the price elasticities. Except for the growth of demand, prices above the long-run profit maximizing curve cannot be maintained without continuously cutting output, resulting in loss of market share and, hence, market power. In this light, the historical pattern is both interesting and understandable. The prices reached as a result of the Iran-Iraq war were sustainable only by continued sacrifice of market share by OPEC. But the loss of market share eroded OPEC's market power until, in 1986, OPEC abandoned the policy of defending higher prices and prices collapsed. Note that prices did not collapse to competitive market levels, but rather to the long-run monopoly price level. Then, with renewed growth of world oil demand and a reduced price incentive to rest of world producers, OPEC began to regain market share. On the same graph are plotted the 1997 Annual Energy Outlook (AEO) Reference Case projections for price and OPEC market share through 2015. Note that the Energy Information Administration (EIA) expects OPEC to regain its former market share sometime between 2005 and 2010. Unless price elasticities have changed substantially, this means regaining its former market power.

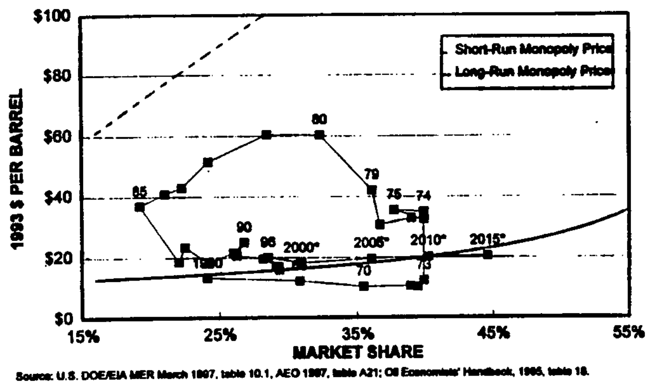


FIGURE 2. OIL PRICES AND CORE OPEC MARKET SHARE HISTORICAL AND PROJECTED

THE COST OF OIL DEPENDENCE TO THE U.S. ECONOMY

Past oil price shocks and noncompetitive pricing of oil have cost the United States economy on the order of $5 trillion dollars (Greene and Leiby, 1993). These phenomena harm the economy in three distinct ways. First, higher oil prices signal the economy that oil is more scarce. As a result, the potential output of the economy, given the same endowments of other resources, is reduced. This is most often referred to as loss of potential Gross Domestic Product (GDP). Price shocks throw the economy into disequilibrium and, since it cannot adjust wages and other prices fast enough, there is a temporary underemployment of resources. These additional losses of GDP are generally termed macroeconomic adjustment losses. Many factors determine the size of GDP losses, but perhaps the best indicator of the economy's vulnerability is the oil cost share of GDP. Today, the oil cost share of GDP is about the same as it was in 1972. Finally, prices above competitive market levels cause a transfer of wealth from oil consumers to oil producers. The transfer from the U.S. economy is exactly equal to the difference in price times the quantity of oil imported. Today, U.S. oil imports match

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[1]Elasticity is a dimensionless parameter defined as the relative change in one variable caused by a relative change in another of 1 unit. Mathematically, the elasticity of y with respect to x is the derivative of the logarithm of y with respect to the logarithm of x. The price elasticity of demand is not necessarily a constant over all price levels. In fact, for equation (1) to be meaningful for realistic values of its short-run parameters, β must be an increasing function of the price of oil.

the highest level ever, 8.5 mmbd, 46% of total oil consumption.

Private markets should take account of some of the costs of oil dependence. The macroeconomic adjustment costs, on the other hand, will not be taken into account, nor will individual oil consumers take account of the fact that if all consumers reduce oil consumption and increase the price elasticity of their demand, world market prices will fall. Thus, the vast majority of the benefits of an economy-wide increase in oil supply and demand elasticities are not reflected in market decisions.

TECHNOLOGY AND PRICE ELASTICITY

Oil dependence has been a serious economic problem in the past, and there is reason to believe it may be again in the future, but is there anything that we can do about it? Just as equation (1) helps us understand the problem it also points toward the solution. If short- and long-run price elasticities of demand and supply can be increased significantly, the market power of the cartel can be greatly reduced. The price elasticity of demand depends on consumer preferences but also on the technology of energy use. Because the transport sector accounts for two-thirds of U.S. petroleum consumption and over 80% of the high-value products that drive the oil market, it is the technology of energy use in the transport sector that matters most.

Technology affects the price elasticity of oil demand in two principle ways: (1) through the efficiency of transport vehicles, and (2) through the transport sector's ability to use alternative, nonpetroleum energy.

As an example of how the efficiency of vehicles affects the price elasticity of oil demand, consider light-duty vehicles which account for more than half of all transportation energy use.[2] Fuel (F) or energy use by light duty vehicles is identically equal to miles traveled (M) divided by the average efficiency (e) of travel (in miles per gallon). Once again, application of the calculus leads to equation (2), which states that the price elasticity of fuel demand ($\beta_{f,p}<0$) depends on the fuel cost per mile (fuel price divided by mpg) elasticity of travel ($\beta_{m,c}<0$) and the fuel price elasticity of efficiency ($\beta_{e,p}>0$).

$$\beta_{f,p} = \left[\beta_{m,c} \times (1-\beta_{e,p}) \right] - \beta_{e,p} \qquad (2)$$

Whatever increases the fuel price elasticity of fuel economy will make the price elasticity of fuel use more elastic (larger in absolute value). We assume for the sake of simplicity that technology does not affect the fuel price elasticity of vehicle travel. Reasonable values of β_m and β_e based on the extant literature (e.g., U.S. DOE/PO, 1996, ch.5) are approximately -0.2 and 0.2. Probably only about half of the elasticity of efficiency is due to technological changes, the rest (about 0.1) being due to consumer choice of size classes, makes and models, and configurations (e.g., engines and transmissions). These are long-run elasticities. In the short-run, the elasticity of travel is about the same and the elasticity of efficiency is perhaps one-tenth as large. Thus, a reasonable long-run value for $\beta_{f,p}$ would be -0.38, and a reasonable short-run value would be about -0.22.

Increasing the fuel price elasticity of efficiency (e = 1/mpg) is accomplished by reducing the cost of increasing vehicle fuel economy. As an example of how technology can do just that, we draw on a recent study of the potential for advanced automotive technologies, such as those being developed by the government/industry Partnership for a New Generation of Vehicles (PNGV) program (U.S. Congress/OTA, 1995). These technologies range from lightweight materials, to hybrid vehicle technology, batteries, lean nitrogen oxides catalysts, and fuel cells. Figure 3 shows the estimated costs of increasing passenger car fuel economy using today's technology according to a recent study by the National Research Council (NRC, 1992), and using advanced technology in the years 2005 and 2015. Smooth quadratic functions have been fitted to the NRC and OTA data. The advanced technology curves are based on the OTA's most optimistic assessment of the potential for technological advances. The curves in Figure 3 represent total costs, whereas the supply curve for fuel economy represents marginal costs, the derivative of total costs, which in this case will be a straight line.

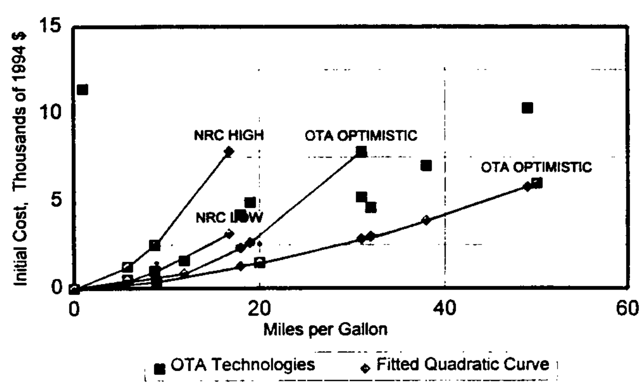

FIGURE 3. ESTIMATED COSTS OF PASSENGER CAR FUEL ECONOMY IMPROVEMENT USING ADVANCED TECHNOLOGIES, TODAY TO 2015

The fuel price elasticity of fuel economy also depends on the demand for fuel economy. Demand curves can be derived based on motorists' willingness to pay for fuel savings. Here we assume that willingness to pay equals the discounted present value of future fuel savings, a straightforward calculation given a few key parameters (an effective discount rate of 15% including the depreciation rate of capital invested in the vehicle, annual miles driven of 14,000 per year when new declining at 4% per year, and a fuel prices of $1.21 and $1.52 per gallon). Changing the price of fuel shifts the demand curve for fuel economy upward. By solving for market equilibrium fuel economies at the two fuel price levels, arc elasticities can be readily computed for the different fuel economy supply curves, and these are shown in Table 1. Advancing technology from today's

[2]Note that the elasticity of oil demand with respect to the price of oil is equal to the sum over all petroleum products of the elasticity of demand for each produce with respect to its own price, times the elasticity of its price with respect to the price of oil, times the product's share of total oil use. Thus, increasing the own price elasticity of demand for all products by 10% would increase the elasticity of oil demand with respect to the price of oil by 10%.

level to the optimistic 2015 curve more than triples the price elasticity of new vehicle fuel economy. With a flatter fuel economy cost curve a given upward shift in the demand curve produces a large increase in mpg. In the long run, the PNGV technology increases the price elasticity of gasoline demand by almost 50%. In the short-run, however, the effect is certain to be much smaller. Indeed, in the first year there may be no effect of technological changes on mpg because of the time required to implement design changes in vehicles. On the other hand, the effect of consumer choice could be greater if the advanced technology caused a wider array of high efficiency models to be available to choose from. A more detailed analysis than we have been able to do thus far would be necessary to meaningfully analyze this question.

TABLE 1. EFFECT OF THE COST OF FUEL ECONOMY ON THE ELASTICITY OF GASOLINE DEMAND

Supply Curve	Initial mpg	Final mpg	long-run $\beta_{c,p}$	long-run $\beta_{f,p}$
NRC High Cost	28.5	29.0	+0.077	-0.341
NRC Low Cost	31.1	32.0	+0.126	-0.380
PNGV: OTA Study	37.3	39.7	+0.274	-0.500

Note: The values of $\beta_{c,p}$ shown in table 1 are the technology component. To get the full value including salesmix shifts, 0.1 is added. The full value is used in computing values for $\beta_{f,p}$.

Another principle means of increasing the price elasticity of petroleum demand is to make it cheaper and easier to introduce nonpetroleum energy sources. Nonpetroleum energy sources can be introduced in two different ways: (1) by blending with conventional fuels (e.g., blending ethanol with gasoline to produce gasohol), and (2) by direct use of neat or near neat alternative fuels by alternative fuel vehicles. Alternative fuel vehicles may be dedicated (able to run only on the alternative fuel) or fuel flexible. Fuel flexible vehicles are especially interesting because of their ability to instantly switch from one fuel to another. But, the effect of flex-fuel vehicles on price elasticity is likely to be constrained by the ability to expand fuel supply. For this reason, alternative fuels that are already ubiquitous (such as electricity or natural gas) would seem to be especially attractive. An electric hybrid vehicle capable of drawing electricity from the grid to recharge its batteries or of running solely on gasoline or diesel is one example.

Evaluating the potential effects of the wide array of alternative fuel options is well beyond the scope of this paper. Instead, a general example of fuel substitution is used to illustrate the principle that alternative fuel technology can directly affect the price elasticity of oil demand. The demand for petroleum fuels (G) is identically equal to the demand for total motor fuels (F) times the market share of petroleum fuels (s_f). By application of calculus, it is easy to show that the price elasticity of demand for petroleum fuels (β_g) equals the product of the price elasticity of demand for all fuels (β_f) and the cost share of petroleum fuels (ω_g), plus the price elasticity of the market share of petroleum fuels (γ_g). This simple relationship is shown in equation (3).

$$\beta_g = \beta_f \omega_g + \gamma_g \qquad (3)$$

If we further assume that each fuel's share is a multinomial logit (MNL) function of the price (P) of the fuel, then by choosing a reasonable value for the coefficient of price in the MNL model we can simulate the effect on the price elasticity of gasoline of improving the alternative fuel and thereby increasing its market share. Certainly other attributes of the fuel, e.g., range, effect on horsepower, availability, etc., distinguish the fuel from gasoline but one can think of translating those attributes into price equivalents and capturing them in a measure of "generalized cost." Using survey data concerning the effect of fuel availability on the choice between two otherwise identical alternative fuels, Greene (1997) estimated a price coefficient of about -10 for such an MNL model with prices measured in 1996 dollars. Since alternative fuels are actually somewhat different, a realistic price coefficient would smaller in absolute value.

In this simple illustration, the effect of improving alternative fuel technology on gasoline price elasticity appears to be quite dramatic. Assuming that gasoline costs $1.25 per gallon, and that the price elasticity of fuel demand is -0.4, the price elasticity of gasoline demand with the alternative fuel priced at $2 per gallon would be -0.407, and the market share of the alternative fuel would be 0.1% (Figure 4). As the price is decreased toward $1.50 per gallon, market share increases to 12%, and the price elasticity of gasoline demand more than quadruples to -1.8. If one thinks of the price of the alternative fuel as a generalized cost incorporating negative aspects of the alternative fuel and the alternative fuel vehicle that uses it, then the effect of decreasing price can be an analogy for improving the technology of alternative fuels and vehicles. Of course, this is a simple illustration which ignores very important aspects of real world markets, such as the time required to expand alternative fuel production and distribution infrastructure. Nonetheless, it suggests that alternative fuels and vehicles technology could potentially have a dramatic impact the price elasticity of oil demand.

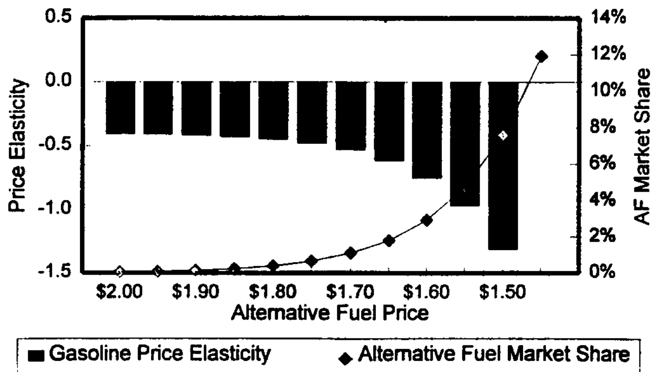

FIGURE 4. ILLUSTRATION OF THE EFFECT ON GASOLINE PRICE ELASTICITY OF THE PRICE AND MARKET SHARE OF AN ALTERNATIVE FUEL

Technology can also profoundly affect the price elasticity of oil supply. The question of whether improvements in oil supply technology, such as 3-D seismic imaging and horizontal drilling, have already had a dramatic impact on world oil supply elasticities has been debated in the literature (see, e.g., Salameh, 1995). The subject, however, is beyond the scope of this paper.

THE VALUE OF PRICE ELASTICITY

It has been demonstrated that the price elasticities of oil supply and demand together with market share determine the market power of the OPEC cartel. The relationships between fuel economy and alternative fuels technologies have been described and illustrated. It remains to show what a significant change in the elasticities of supply and demand might be worth to the United States' economy. Greene, Jones and Leiby (1995) simulated the effect of a hypothetical reduction in oil supply from OPEC members starting in the year 2005. Beginning with the EIA's 1995 AEO Reference Case Projection, they assumed a cutback of 13% of OPEC supply in 2005, followed by a further reduction of 8% in 2006, versus the Reference Case. After 2006, OPEC was assumed to gradually increase output. In the simulation, prices jumped from $22 per barrel to $56 in 2005, and declined to $48 in 2006 (1995 dollars). Prices stabilized at about $30 per barrel through 2010. Greene, et al., estimated the cost to the U.S. economy of such a price shock and subsequent restriction of output by OPEC at $550 billion (1995 $). Almost $150 billion of the total losses were transfer of wealth, the rest being GDP losses.

Greene, et al., then reestimated costs, assuming that price elasticities began linearly increasing after 1995 until they were doubled in 2005. Doubling the world price elasticities of oil supply and demand reduced the economic costs of oil dependence to the U.S. over the entire period, given the hypothetical oil price shock, by $950 billion present value, discounted at 4%/yr. Even doubling only U.S. elasticities saved the U.S. economy $600 billion. Lesser increases in price elasticities also produced substantial economic savings (Figure 5). Finally, doubling price elasticities produced substantial economic savings for the U.S. ($670 billion) even in the absence of a price shock, due to the fact that oil prices in the Reference Case exceed estimated competitive market levels. Thus, increasing the price elasticities of oil supply and demand appears to be a robust strategy that will produce very large benefits so long as the OPEC cartel is exercising any market power in world oil markets.

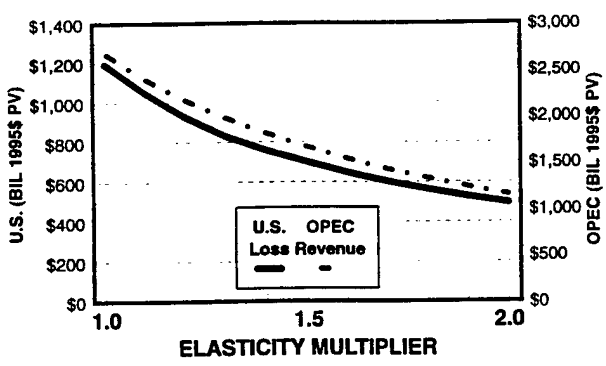

FIGURE 5. EFFECT OF OIL PRICE ELASTICITIES ON THE COSTS OF OIL DEPENDENCE

Based on these results, a simple decision model can be used to explore the potential value of technology R&D. Consider four potential states of the world based on: (1) success or failure of an R&D program to increase the price elasticities of oil demand and supply, and (2) the occurrence or non-occurrence of an oil price shock. Assuming the probability of an oil price shock is 50%, and using the economic cost savings set forth above, we can calculate the value of R&D as a function of the probability of its success. Of course, success or failure of technology R&D is almost certain to be a matter of degree but it is represented as either-or here for simplicity. In fact, given the shape of the cost v. elasticity curve shown in Figure 3, it would not be too unreasonable to interpret an 0.1 probability of success as equal to a certainty of a 10% increase in elasticity. Table 2 shows a set of values in terms of annualized willingness to pay over the fifteen-year period 1996 to 2010. Expected present values of the hypothetical R&D programs range from $81 billion to $812 billion. In terms of an annual willingness to pay (analogous to the maximum funding level for an R&D program) values range from $7 billion to $73 billion.

TABLE 2. ANNUAL WILLINGNESS TO PAY FOR (VALUE OF) R&D TO INCREASE OIL PRICE ELASTICITIES
(Billions of 1995 $, present value discounted at 4% per annum)

Probability of R&D Success	Expected Cumulative Benefit	Annual W-T-P
0.10	$81	$7
0.25	$203	$18
0.50	$406	$37
0.75	$609	$55
1.00	$812	$73

SUMMARY AND CONCLUSIONS

Oil dependence has cost the U.S. economy dearly in the past and is likely to continue to do so in the future, unless the fundamental parameters of oil supply and demand change. Technology plays a major role in determining these parameters. It has been demonstrated that major changes in the energy efficiency and alternative fuel technologies can, in theory at least, have a major impact on the elasticity of oil demand in the transport sector. If such impacts could be achieved, they might justify a U.S. R&D effort aimed at both supply and demand technologies of up to $70 billion dollars per year, depending on one's assumptions about the probability of R&D success and, to a lesser extent, the probability of future oil price shocks. This should not be interpreted as solely a U.S. government R&D effort, since the private sector has some incentive to address the problem of oil dependence, as well. Most of the benefit of reducing oil dependence, however, is not reflected in private incentives and therefore a substantial share of the funding should come from public sources.

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