Transportation's Oil Dependence and Energy Security in the 21st Century

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1. INTRODUCTION

The persistent and in many parts of the world rapid motorization of transport is intensifying global dependence on petroleum. Transportation's global oil dependence poses real energy security risks for the first few decades of the 21st century, at least. At the same time, the world economy is in no danger of "running out of oil" during the next century. In this essay, I will attempt to explain this paradox of oil scarcity and its implications for energy security in an increasingly motorized world. The scarcity which immediately threatens world energy security today is an economic, rather than a physical or geologic scarcity. Economic scarcity does depend on geology, but, more to the point, it can be created by anticompetitive (monopolistic) behavior, or may temporarily result from any of a variety of shocks to which the world's oil producing regions are subject. The inability of oil markets to adjust rapidly to sudden changes in supply, enables supply shocks, whether deliberate or inadvertent, to produce enormous increases in oil prices and, consequently, immense profits for oil producers together with massive losses for oil consumers.

The adequacy of fossil energy resources is an important issue from the perspective of the sustainability of human society, as are the consequences of its use. While there appear to be more than enough fossil energy resources to last 100 years, use of this resource by conventional means would produce cumulative carbon emissions six to seven times the current atmospheric carbon content of 760 GtC (WEC, 1995). Thus, the immediate oil dependence problem must be understood in the context of global efforts to address associated problems of urban air pollution, greenhouse gas emissions and, above all, the sustainability of modern society. Each one of these motivations to transform transportation's oil dependence arises from a kind of market failure. Urban air pollution and greenhouse gas emissions are environmental externalities. The failure of market systems to adequately consider the long-run sustainability of society is yet a different kind of market failure that is at present still being defined (Pearce and Warford, 1993). At the heart of the oil security problem is the potential for market power to be exploited in imperfectly competitive energy markets. All of these transportation energy problems appear to share a common solution: the transformation of transportation technologies to better achieve society's environmental and economic goals. The importance of changes in transportation technology to reducing oil dependence will be briefly explored in this paper.

2. BACKGROUND

Over the past 25 years, the Organization of Petroleum Exporting Countries (OPEC) cartel has used its market power to create or capitalize on oil market disruptions. In October of 1973, the Arab members of OPEC announced an oil boycott against countries that aided Israel during the "October War." From September 1973 to December 1973, they reduced their crude oil production by 4.2 million barrels per day (mmbd), about 7 percent of 1972 world oil supply (U.S. DOE/EIA, 1997b, table 4.4). World oil prices doubled. Again in 1979-80 the loss of 5.4 mmbd of production from warring Iran and Iraq, about 8 percent of world supply, produced another doubling in the price of oil. Following both shocks, OPEC members restrained their oil output, with the expressed intent of maintaining the new, higher price of oil. From May to December of 1990, total oil output from Kuwait and Iraq fell by 4.8 mmbd, about 7.6 percent of world production. From the second to the fourth quarter of 1990, oil prices jumped from $18.50 to $34.50 per barrel (1995 $). In contrast to previous price shocks, this one was short-lived as OPEC members, especially Saudi Arabia, responded by increasing output by more than 3 mmbd to replace most of the shortfall (Tatom, 1993, p. 138).

The oil market machinations of the 1970s and 1980s were very costly to oil consumers and very profitable for oil producers. The price shocks and subsequently higher price levels of the 1970s and 1980s cost the economies of oil importing nations trillions of dollars (U.S. DOE, 1988, p. 6). Greene and Leiby (Greene and Leiby, 1993) estimate the costs from 1972 to 1991 to the U.S. economy alone at over $4 trillion dollars, 80 percent as large as the Nation's total expenditures on national defense over the same period.[1] At the same time, many OPEC states were transformed from developing economy status to among the richest nations on earth. In 1972, OPEC revenues amounted to $24 billion per annum. After the 1979-80 oil price shock, OPEC collected $287 billion from oil consumers. Today, after ten years of cheaper and plentiful oil supplies, we seem to think that the oil problems of the past are behind us. But are they?

[1]Subsequently, Greene and Leiby discovered an error in their calculations that resulted in an overestimate of the transfer of wealth component of oil costs by approximately 20 percent, with result that total costs were overestimated by about 5 percent.

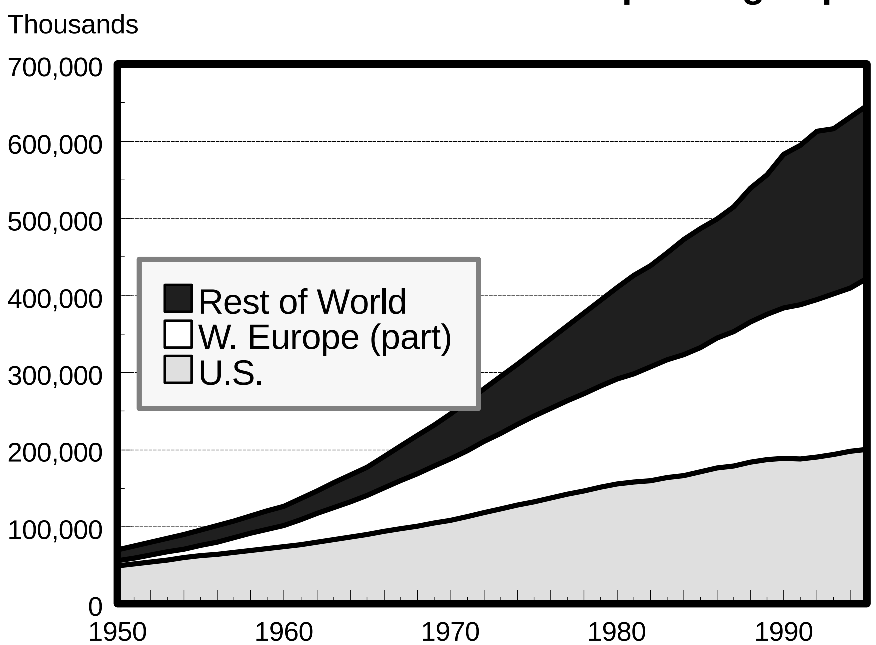
After the first oil crisis in 1973-74, many believed that oil resources had suddenly become permanently, physically scarce, and that oil prices would inexorably continue to rise in the future. This view turned out to be wrong. High oil prices, sustained by OPEC's continuing efforts to restrain production, depressed oil demand and stimulated supply from non-OPEC producers. World oil demand, which had been growing at nearly 8 percent per annum since 1960 until just before the 1973-74 price shock, slowed to an average annual rate of 0.4 percent per annum from 1973 to 1985 (U.S. DOE/EIA, 1996, table 11.9). OPEC oil production, which had been increasing at an annual rate in excess of 10 percent since 1960, actually fell at the rate of 5 percent per year from 1973 to 1985. Oil production by non-OPEC countries, which had been increasing at 5.5 percent annually prior to the first oil price shock, grew at 3.5 percent per annum from 1973 to 1985 (U.S. DOE/EIA, 1996, table 11.5. As a consequence, OPEC's share of the world oil market shrank from 55 percent in 1973 to 30 percent in 1985. As will be explained below, loss of market share means loss of market power for a cartel. Finally unable to continue to maintain high oil prices by means of further production cuts, OPEC members began increasing production. Just as suddenly as they had risen, oil prices collapsed from $34.43 per barrel in 1985 to $17.37 in 1986 (1992 $) (U.S. DOE/EIA, 1996, table 5.19).

The oil price collapse of 1986 dispelled the myth of oil's physical scarcity. OPEC, it seemed, had been vanquished by the relentless force of the marketplace. Unfortunately, the reports of OPEC's death were greatly exaggerated. Since 1986, oil production by non-OPEC nations has declined by 0.5 percent per year, while OPEC's output has increased at the modest rate of 1 percent per year. As a result, OPEC's share of the world crude oil market has grown from 30 percent to 42 percent.

It is tempting to look back at 15 years of lower oil prices, slower growth in petroleum demand, especially in the economies of Western Europe, Japan, the U.S. and countries of the former Soviet Union, as well as the recent successes in non-OPEC oil production and conclude that oil dependence is no longer a serious security problem. But this would be shortsighted. World petroleum consumption is becoming increasingly concentrated in the transport sector, a sector that remains nearly totally dependent on oil. In the U.S., past technology-based improvements in transportation energy efficiency appear to have run their course (U.S. DOT/BTS, 1997, Ch. 5), promising a faster rate of growth in demand in the future. In the rest of the world, transport's energy demand is growing faster as it becomes increasingly motorized. In 1950, 90 percent of the world's 50 million cars and trucks could be found in North America or Europe. Today, the world motor vehicle fleet stands at 650 million and is expected to exceed 800 million by 2010 (World Resources Institute, 1996). Motorization and motor fuel demand are growing fastest outside of the U.S. For two decades following the 1973-74 oil price shock, U.S. transport energy demand grew at about 1 percent per year, while demand in the rest of the OECD and in formerly communist countries grew at 2 percent per year (Greene, 1996, p.2). In the past few years, the rate of growth of U.S. transport energy demand has accelerated to nearly 2 percent per year. Outside of the OECD, transport energy use has been growing at more than 4 percent per year.

Whether in the future oil producers will be able to manipulate the economic scarcity of oil to their own benefit and at the cost of oil consumers depends on the fundamental factors that permit

World Motor Vehicle Stocks Are Expanding Rapidly



Source: AAMA, World Motor Vehicle Data 1995.

an oil cartel to wield market power, and also how the noncompetitive pricing of oil and especially oil price shocks harm an economy. These factors are key to understanding whether similar oil price shocks could happen again, whether the world's economy remains vulnerable, and what, if anything, can be done about it.

3. MARKET POWER AND THE ECONOMIC SCARCITY OF OIL

From the perspective of energy markets, oil is not an exhaustible resource. This once heretical view is now widely accepted among resource economists (Banks, 1986; Adelman, 1990; Gordon, 1994), for two reasons. First, until 1973, more oil has always been discovered and developed, and without any increase in its real price. Imagine a world in which more oil can be found, merely by looking for it; a world in which one can, with extra effort, squeeze more oil from already depleted fields; a world in which things that are not oil can be changed into oil, and in which the same amount of work can be done with much less oil than previously required. Of course, this is the real world. It is the world of the fixed, finite stock of oil that will someday be used up that is make believe.

The second reason that markets do not treat oil as if it were exhaustible is that the world's endowment of oil and oil-like resources is known to be large relative to current rates of consumption. How large the world's oil resources are depends on how one defines resources, and how one defines oil. This is not merely a flippant remark, because technology defines both of these terms, and technology is ever changing. If we use the concept of proven reserves, oil that is known to exist and can be produced economically at prevailing prices using current technology, the world has approximately 1 trillion barrels. The world presently produces about 24 billion barrels per year (U.S. DOE/EIA, 1997a, table 10.1b). This gives a reserve-to-production ratio (R/P, a measure of size more than a prediction of lifetime) of 42 years (Table 1). The U.S. Geological Survey estimates that the world's ultimate resources of conventional oil (discovered and undiscovered) amounts to 1.7 trillion barrels, raising R/P to 71 years (Masters et al., 1994). But current methods of oil extraction recover only 34 percent of the oil in the ground. The American Petroleum Institute estimates that if the technology of oil recovery improves as it has in the past, 2.8 trillion barrels of oil eventually could be produced (Porter, 1995) for an R/P of 117 years. If known reserves of unconventional, heavy and extra-heavy oil could be economically refined, oil resources would expand to 3.4 trillion barrels (R/P = 142 yrs.). Beyond this, there are an estimated 14 trillion barrels of oil equivalent of oil shale and tar sands that could be used, technology and economics permitting, and if the world were willing to suffer the environmental consequences. When will the world "run out" of oil? Never.

The problem is not that the world is about to "run out" of oil.[2] It is that the world's conventional oil resources are concentrated in relatively few countries who are thereby able to manipulate the economic scarcity of oil to their advantage, and who have done so in the past. The best estimates of the world's conventional oil resources indicate that OPEC owns more than half. Credible estimates of OPEC's share range from a low of 55 percent (Masters et al., 1994) to a high of 64 percent (OPEC Secretariat, 1995).[3] The difference is due to greater optimism on the part of analysts at the U.S. G.S. about the petroleum resources in the Former Soviet Union (Ulmishek and Masters, 1993) and, to a lesser extent, the U.S., Canada, Mexico, and China.

Table 1. World Oil Resource Estimates

Category of Resource	Amount	R/P "Life" of Resource Base at 1995 Rate	R/P "Life" at 3% Annual Growth
Proven Reserves	1 trillion barrels	42 yrs.	27 yrs.
USGS Identified Reserves	1.1 trillion bbls.	46 yrs.	29 yrs.
USGS Ultimate Resources	1.7 trillion bbls.	71 yrs.	38 yrs.
With Enhanced Oil Recovery	2.8 trillion bbls.	117 yrs.	50 yrs.
With USGS Heavy and Extra Heavy Oil	3.4 trillion bbls.	142 yrs.	55 yrs.
With Oil Shale and Tar Sands	17.4 trillion bbls.	725 yrs.	104 yrs.

Because OPEC members are drawing down their reserves at half the rate of the rest of the world's oil producers, it seems almost inevitable that OPEC's share of the world oil market will grow (Masters et al., 1994). For example, the U.S. Energy Information Administration predicts that OPEC's share of the world oil market will rise from its current level of 42 percent to reach 48 percent by 2005, and will climb to 52 percent by 2010 (U.S. DOE/EIA, 1996, tables 10 & 11).[4]

4. THE DETERMINANTS OF OPEC MARKET POWER

[2]More importantly, from the perspective of sustainability, 50 or even 150 years is not a very long time, considering that energy for such an essential economic activity hangs in the balance.

[3]Similar estimates have recently been produced by Petroconsultants (1996), Campbell (1995), and Miramadi and Ismail (1993).

[4]The most recent DOE/EIA projections are more optimistic, foreseeing OPEC's market share at only 42 percent in 2005 and 45 percent by 2015. World oil demand is projected to grow at only 2 percent per year, while non-OPEC oil production increases at 3 percent per year (U.S.DOE/EIA, 1997c, table A47).

Objective conditions, namely the distribution of world oil resources, the size and structure of oil consuming economies, and the technologies of oil production and consumption, determine the potential market power of the OPEC cartel. Given information about these factors, economic theory can predict what OPEC could do, and even what it would be most profitable for OPEC to do. But it cannot predict what OPEC will do. This would require predicting the behavior of a confederation of sovereign states, a task that is largely outside the domain of economic analysis. Yet, by revealing what power the OPEC cartel could exert on energy markets, and what would be in its economic interest, economic analysis provides valuable insights into how world oil markets are likely to behave in the future.

A fundamental conclusion of the theory of competitive markets is that production of a commodity will expand until the cost of the last unit produced (C) equals the market price (P). For a competitive market to exist, no one producer (or colluding group of producers) must be able to affect the market price. All must be "price takers." A producer with market power, on the other hand, finds that by restricting production, it can cause prices to increase. The price that a monopolist should charge to make the greatest profit is given by a simple formula (see Figure 2) that depends on the extent to which demand responds to changes in price (i.e., the "price elasticity" of demand, which is the percent change in the quantity demanded for a 1 percent change in price). Referring to Figure 2, if the price elasticity of demand is -2 (a 1 percent price increase will cause demand to fall by 2 percent), the ratio P/C will equal 1/(½) = 2, implying that the price that maximizes the monopolist's profits will be twice the competitive market price.[5]

When a producer does not control the entire market, its market power is limited by the ability of other producers to respond to its pricing and production decisions. This is the position in which OPEC finds itself. Whereas OPEC can coordinate (albeit imperfectly) its production decisions and influence market prices, the rest of the world's producers behave competitively (as price takers) (Dahl and Yücel, 1991; Jones, 1990; Griffen, 1985). In economic jargon, OPEC is an imperfect monopolistic cartel of the von Stackelberg type (Mabor, 1992). For a von Stackelberg monopolist, the profit-maximizing price depends not only on the price elasticity of demand, but on its own share of the market, and on the supply response of the rest of the world (Figure 2). The "rest-of-world" supply response is defined as the number of barrels the rest of the world will supply, at constant market price, in response to a one barrel reduction in supply from OPEC. If the supply response equals -1, then a 1 barrel reduction in supply by OPEC will be met by a 1 barrel increase in supply by the rest of the world's producers, the market price remaining

[5]The formulas in Figure 2 cannot admit any and all values of price elasticities and other parameters. In particular, the monopolist's pricing equation is undefined for price elasticities between -1 and 0, inclusive. Intuitively, if demand is too unresponsive to price, the monopolist could charge any price it wished (this might occur, for example, if a firm had the monopoly on food, water, or air). In most cases where demand is inelastic, however, price elasticities do not remain constant but tend to increase with increasing price, so that a solution is ultimately reached.

Figure 2. Noncompetitive Pricing

SIMPLE MONOPOLY

$$\frac{P}{C} = \frac{1}{\left(1 + \frac{1}{\beta}\right)}$$

P = price
C = cost of production
β = price elasticity of oil demand

STACKELBERG MONOPOLY

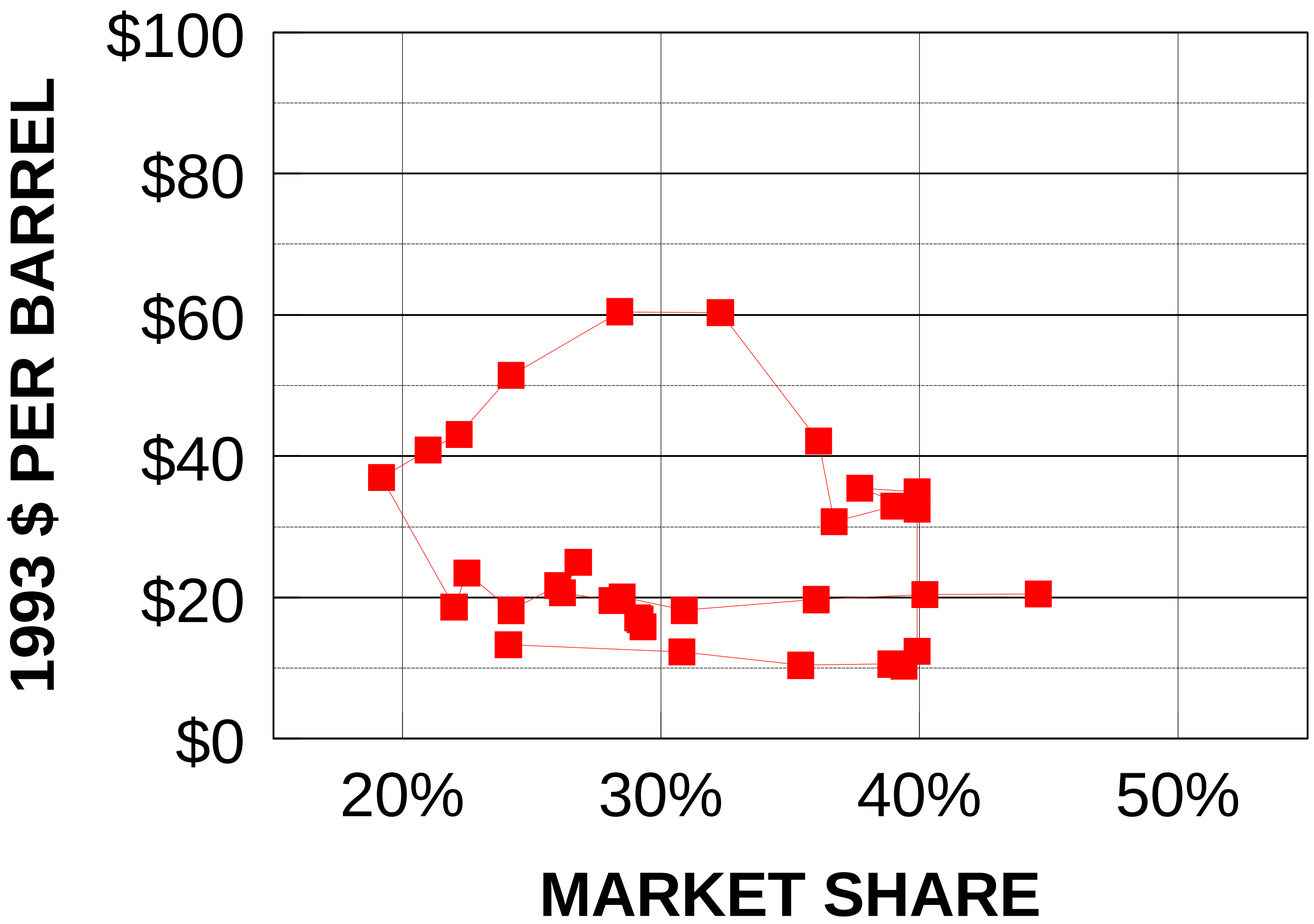
$$\frac{P}{C} = \frac{1}{\left(1 + \left[\frac{1}{\beta}\,\sigma\,(\delta + 1)\right]\right)}$$

σ = cartel's market share
δ = "rest of world's" supply response

unchanged. If this were the case, OPEC would have no market power (i.e., it's profits would be maximized when P/C = 1).

Over a short period of time, the ability of producers and consumers to respond to a change in the price of oil is far more limited than it is in the long run. It takes time to discover, develop, and bring new oil resources to market. It takes even longer to replace the capital stocks of oil-using automobiles, airplanes, and industrial plants. Typically, the long-run response to changes in oil prices are on the order of ten times the response that can be accomplished in one year. This fundamental fact has enormously important implications for the world oil market. It means that the price that yields OPEC the greatest profits in the short-run cannot be sustained over the long-run. By substituting into the von Stackelberg formula first short-run, and then long-run values for the price elasticity of oil demand and the rest-of-world supply response, one can draw two curves, showing the short-run and long-run, maximum profit prices for OPEC as a function of its market share (Figure 3). If one assumes a competitive price (C in the formulas in Figure 1) of $10.30 per barrel (the 1972 price of oil in 1995 $), then the ratio P/C can be translated into the market price of oil, as in Figure 3.

Oil Prices and Core OPEC Market Share
Historical and Projected



Source: U.S. DOE/EIA MER March 1997, table 10.1, The upper curve in Figure 3 shows the prices that would give OPEC maximum profit for a single year, but which could not be sustained for more than one year. The lower curve shows prices that could be sustained indefinitely in a static market. When world oil demand is growing, however, prices above the lower, long-run curve can be sustained indefinitely. Because knowledge of price elasticity and supply response parameters is never perfect, these curves should be considered indicative rather than precise. Nonetheless, they are useful for illustrating several important points.

Plotting historical world oil prices and the market share of OPEC core[6] nations in Figure 3, reveals why oil prices collapsed in 1986 and why OPEC's influence on world oil markets faded. Prior to 1973, with oil prices below even the long-run price curve, OPEC's market share grew rapidly as world oil demand increased at the rate of about 8 percent per year. In 1973 and 1974, OPEC members restricted output causing the first oil price shock, but also halting the growth of their market share. In a static market, OPEC would have had to sacrifice market share in order to cause prices to rise. The price shocks of 1979 and 1980 were accompanied by just such a loss of market share. At this point, OPEC consciously decided to defend the higher price level by cutting back on production (Al-Fathi, 1990, pp. 2-3). But reducing production means giving up market share, and giving up market share means giving up market power. This inevitably led to a downward spiral of OPEC revenues, from $287 billion in 1980 to $131 billion in 1985. As the untenability of the situation became clear, OPEC cohesiveness cracked, with Iraq first jumping ship and increasing production in 1985. When Saudi Arabia abandoned the defense of higher prices in 1986, oil prices collapsed. Even so, prices did not collapse to pre-1972 levels, but rather to levels closer to the long-run, sustainable monopoly price curve.

Since 1985, OPEC has gradually regained market share, as world oil demand began increasing once again. The U.S. Department of Energy's 1996 oil price and OPEC output projections (also shown in Figure 3), reflect the seemingly inevitable recapturing of market share by OPEC, which holds the majority of the world's oil resources, the overwhelming majority of the world's low-cost reserves, and which is drawing down its reserves at half the rate of the rest of the world.

5. COSTS OF OIL DEPENDENCE

Opportunistic use of market power generated fabulous profits for OPEC members during the 1970s and 1980s, but also caused enormous losses to oil consuming economies. Oil price shocks and noncompetitive oil pricing inflict three types of costs on oil consumers: (1) wealth is transferred from oil consumers to producers, (2) the economy's overall ability to produce is diminished by oil's greater economic scarcity, and (3) when price movements are sudden and drastic, inflation and unemployment cause additional losses of output. These three components

[6]This reflects the theory that a core group of OPEC members comprise the functional cartel. These core members are Saudi Arabia, Kuwait, Iraq, Iran, the United Arab Emirates and Libya.

are distinct and additive. They do harm to all economies that import and use significant amounts of oil.

Transfer of wealth is the most straightforward component of the costs of oil dependence. When prices rise above normal competitive market levels, wealth is transferred from oil importing economies to oil exporting economies. The quantity of wealth transfer is equal to the quantity of oil imported, times the difference between the actual market price and the normal competitive market price. For instance, in 1980 the United States imported 2.3 billion barrels of oil at an average price of $56 per barrel. If the price of oil in a competitive market would have been $10 per barrel, as some energy economists believe (Berg et al., 1997, p. 502; Griffen and Vielhaber, 1994; Adelman, 1989; Morison, 1987; Brown, 1987), then the transfer of wealth from the U.S. economy to oil producers that year amounted to $114 billion (1995 $). Over the period 1972 to 1996, noncompetitive oil pricing cost the U.S. economy approximately $1.4 trillion (1996 $) in transferred wealth. Vulnerability to transfer of wealth is directly proportional to the quantity of oil imported.

When oil prices rise, they signal that oil has become more scarce. It matters little whether the price rise is due to physical scarcity or the use of market power. A world in which oil is more scarce is a harder world in which to make a living. In other words, there is a loss of the potential to produce economic output. The size of the loss depends on how much oil an economy consumes, and how readily it can substitute other factors of production for oil. Whether prices rise suddenly or gradually, there is still a loss of potential GDP.

When prices rise suddenly and drastically, an economy cannot adjust immediately to the change. The new oil price regime requires accompanying adjustments in wages and interest rates, and changes the relative amounts of capital, labor, energy, and materials needed to produce most efficiently. But labor and capital markets need time to adjust, and the technology embodied in capital equipment cannot be instantaneously transformed. The result is less than full employment of the factors of production, and further losses of GDP. Such “macroeconomic adjustment” losses cause GDP to fall below the full employment GDP, which has already been reduced by the impact of higher oil prices on the economy’s potential GDP.

While there are a great many estimates of the combined effect of the two kinds of GDP losses, much less is known about the relative sizes of the components. Numerous empirical and simulation studies in the U.S. over the past twenty years suggest that a doubling of oil prices reduces U.S. GDP by about 5 percent for several years (Greene et al, 1995, pp. 21-25 for a brief review). The size of the impact in any given year is related to total expenditures on oil as a percent of GDP. That is, the larger the share of expenditures that goes to oil, the more damaging an oil price shock will be to the economy, all else equal.

6. IS OPEC DEAD?

The collapse of oil prices in 1986 and the ensuing decade of lower oil prices have convinced some that OPEC will never regain control of world oil markets. The creation of the strategic petroleum reserves, deregulation of energy markets, establishment of an oil futures market, improving relations in the Middle East, the U.S. military presence in Saudi Arabia, and downstream investments by OPEC have all been cited as reasons why the oil dependence issue is passé. None of these objections, however, affects the fundamental determinants of OPEC market power, as shown in Figure 2. Still others argue that the experience of the 1980s taught OPEC a lesson that they will not try to repeat. Of course, it was that "lesson" that made them rich.

Certainly, there have been some changes for the better. Since 1985, world oil demand has been growing at an average rate of 1.8 percent per annum, far less than the 8 percent rate that preceded the first oil price shock. Since 1994, however, oil demand has grown at a 2.5 percent annual rate and may be accelerating. At 42 percent of world crude oil supply, OPEC's market share remains below 50 percent. There is evidence that technological advances, such as 3-D seismic imaging, horizontal drilling and advances in off-shore drilling methods have reduced the cost of finding and developing oil resources outside of OPEC (Ismail, 1994). It is possible that such changes have increased the rest-of-world supply response, thereby weakening OPEC's market power. Some are clearly convinced that this is the case (U.S. DOE/EIA, 1997c) but others (Salameh, 1995) are skeptical. This is an important subject and worthy of careful investigation. On the other hand, the greater concentration of oil use in the transportation sector may have decreased the price elasticity of demand, which would strengthen OPEC's market power (Gately and Rappoport, 1988; Dargay and Gately, 1994).

7. MOTIVE AND OPPORTUNITY

Simulations of possible future oil supply reductions by OPEC suggest that the cartel will have both the opportunity and the motive to create price shocks and profit from them. Suranovic (1994), confirming an earlier analysis by Wirl (1985), demonstrated that successive oil price shocks produced the maximum profit for OPEC producers. The U.S. DOE/EIA (1994, p. 22) showed that the equivalent of a 5.25 million barrel per day supply shortfall, even as soon as the year 2000, would likely cause oil prices to rise to $55 per barrel. Greene et al. (1995) simulated a 2-year OPEC supply curtailment in the year 2005 similar in size to those of 1973-74 and 1979-80, followed by very gradual increase in OPEC output through 2010. They concluded that the shock would boost OPEC revenues about $600 billion, while the U.S. economy would lose a half trillion dollars as a result. These simulations take into account the now slower growth of oil demand, but do not explicitly address changes in the technology of oil supply.

Both Suranovic (1994) and Greene et al. (1995) assessed the ability of strategic petroleum reserves to defend against a major, sustained supply curtailment, and concluded that they would be of little help. This may surprise some, but it is relatively easy to understand. The total world oil supply shortfall in the Greene et al. simulations amounts to 19 billion barrels. Even the entire strategic reserves of all OECD countries could cover only 5 percent of the total shortfall. Strategic reserves can work well for smaller supply disruptions, and do have some beneficial effect even in the event of a protracted supply curtailment. However, a panacea for energy security they are not.

Creating economic scarcity through the use of market power is beneficial to oil producers, harmful to oil consumers. The opportunity to do so can arise in any of a number of ways. We have already seen oil market disruptions triggered by a boycott by Arab OPEC members of nations supporting Israel in the 1973 October War, a bloody war between Iran and Iraq in 1979-80, and the invasion of Kuwait by Iraq in 1990-91. Future price shocks could be caused by deliberate action to curtail supplies, by wars, insurrections, terrorism, or natural disasters. Depending on the circumstances, OPEC could choose to capitalize on the opportunity and rake in enormous profits or elect to increase production and mitigate the price increase, as Saudi Arabia chose to do in 1991. It seems reasonable to assume that the more money there is to be made, the more likely it is that an opportunity to profit from an oil market disruption will be found.

8. 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 can be done about it? Just as the von Stackelberg equation 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 more importantly on the technology of energy use. Because the transport sector accounts for the majority of world petroleum consumption and an even greater percentage 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.[7] 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). Application of the calculus leads to equation (1), 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 ($\beta_{e,p}>0$).

$$\beta_{f,p} = \left[\beta_{m,c} \times (1-\beta_{e,p}) \right] - \beta_{e,p} \qquad \textbf{(3)}$$

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 $\beta_{m,c}$ and $\beta_{e,p}$, based on the extant literature (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 4 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 according to a study by the OTA (1995). 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 4 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.

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

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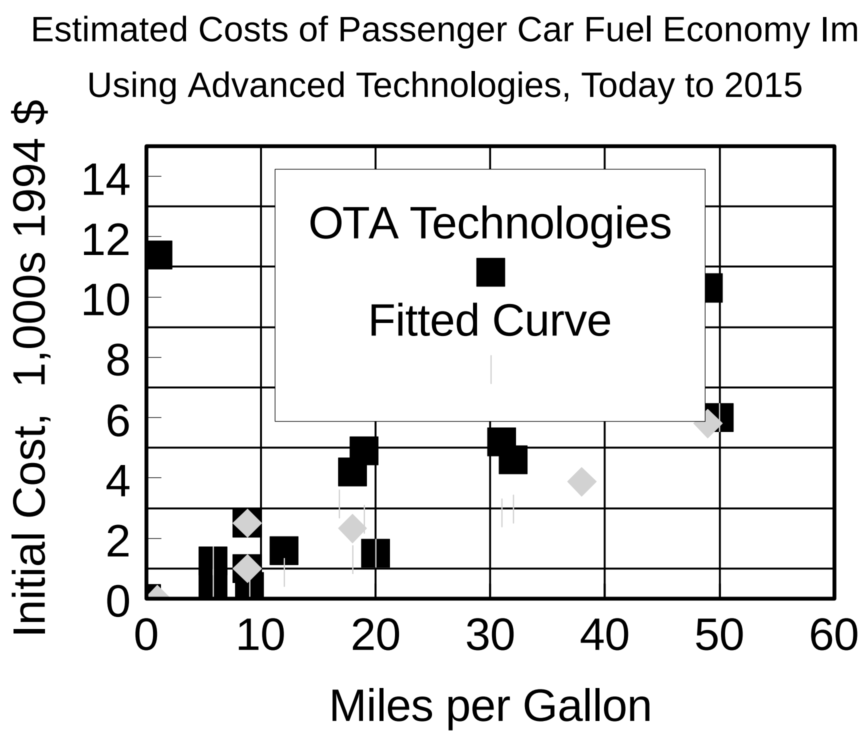
[7]Note that the elasticity of oil demand with respect to the price of oil is equal to the sum over all petroleum products of the elasticity of demand for each product with respect to its own price, times the elasticity of its price with respect to the price of oil, times the product's share of total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


Estimated Costs of Passenger Car Fuel Economy Im
Using Advanced Technologies, Today to 2015
Initial Cost, 1,000s 1994 $
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
Miles per Gallon
OTA Technologies
Fitted Curve

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 percent including the depreciation rate of capital invested in the vehicle, annual miles driven of 14,000 per year when new declining at 4 percent 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 2. Advancing technology from today's 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 percent. 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 2. Effect of the Cost of Fuel Economy On the Elasticity of Gasoline Demand

Supply Curve	Initial mpg	Final mpg	long-run $\beta_{e,p}$	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 $\beta_{e,p}$ 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 (2).

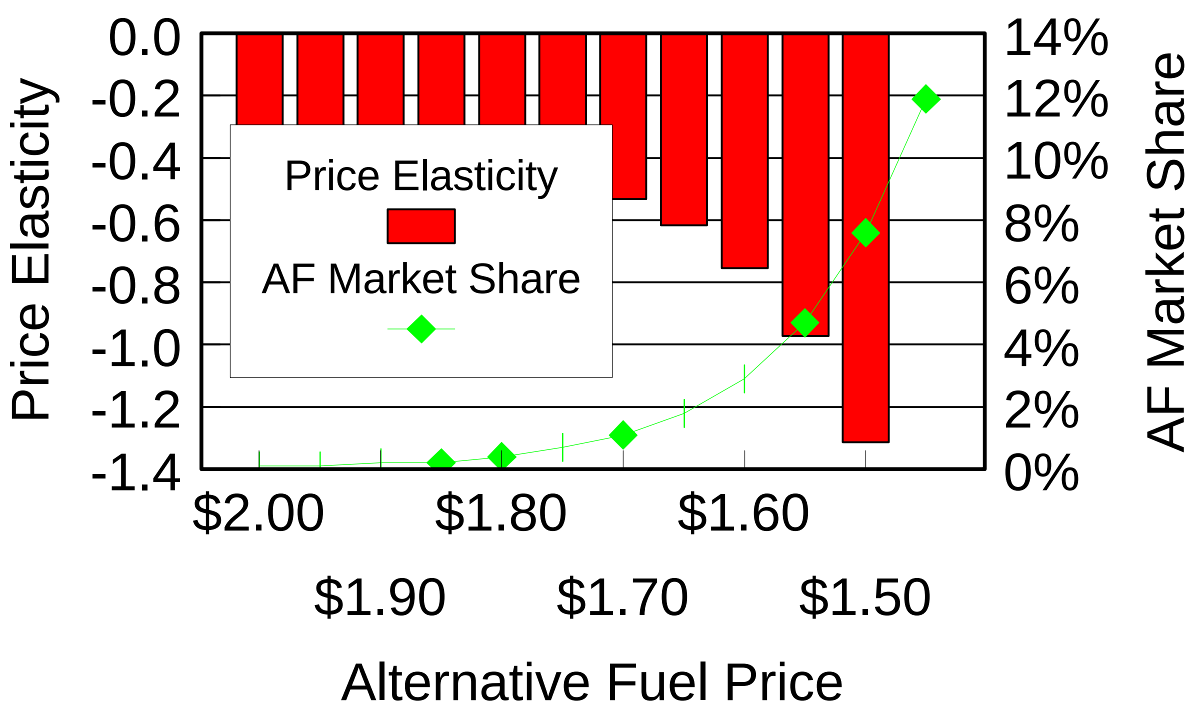
$$\beta_g = \beta_f \, \omega_g + \gamma_g \qquad \textbf{(4)}$$

If we further assume that each fuel's share is a multinomial logit (MNL) function of the price (P) of the fuel (Train, 1986), 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 be 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 percent (Figure 5). As the price is decreased toward $1.50 per gallon, market share increases to 12 percent, 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 on the price elasticity of oil demand.

Technology can also profoundly affect the price elasticity of oil supply. It appears likely that improvements in oil supply technology, such as 3-D seismic imaging and horizontal drilling, have had an impact on world oil supply elasticities (Fagan, 1997; Salameh, 1995) but the size of that impact has yet to be measured. Improvements in technologies for converting natural gas into liquid fuels (such as the Fischer-Tropsch processes for producing synthetic gasoline and diesel), plus a greater willingness to pay for cleaner transport fuels, all offer the potential to increase the elasticity of petroleum product supply. There appears to be a growing consensus among energy forecasters that technological advances will permit greater oil supply from non-OPEC sources

As the Price of an Alternative Fuel Converges on of Gasoline, both Market Share and Elastiticy In



than previously thought and that this will slow the rate of growth of OPEC's market share over the next 20 years (U.S. DOE/EIA, 1997c; WEC, 1995).

9. 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. To some extent, we can rely on the marketplace to develop the needed technologies. Some of the costs of oil dependence are born directly by producers and consumers and, to the extent that oil prices signal scarcity and the market anticipates future price shocks, these costs will be internal to market decisions. But much of the cost of oil dependence is a societal cost that markets will ignore (Broadman, 1986), and there are other important social costs of oil use that result from other market failures, such as environmental pollution and the sustainability of our current energy system (Martin et al., 1996). Because of this, oil dependence is an important public policy issue, one that we have virtually ignored for the past decade. It is now past time to give it the serious attention it deserves.

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