OPEC and the Costs to the U.S. Economy of Oil Dependence: 1970-2010

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Matthew N. Murray, PhD
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Howard H. Baker, Jr.

INTRODUCTION

Since the 1970s, oil dependence has been recognized as an important national security and economic problem for the United States (Deutch, Schlesinger and Victor 2006). To a great extent, although not entirely, the national security issues associated with oil dependence are a consequence of its potential damage to the U.S. economy. To inform decisions about national energy policy it is therefore important to measure those costs.

In 1993 researchers at Oak Ridge National Laboratory began retrospectively estimating the direct economic costs of oil dependence (Greene and Leiby 1993). In 2006, following a methodology proposed by the National Research Council’s (NRC’s) Committee on Prospective Benefits of the Department of Energy’s Energy Efficiency and Fossil Energy R&D Programs (NRC 2005), the researchers formalized and refined the methodology for retrospective and prospective cost estimation in the Oil Security Metrics Model (OSMM) (Greene and Leiby 2006). The model has since been used not only to estimate past costs but to analyze the potential effectiveness of policies on likely future costs (Greene 2010).

Past estimates showed that oil dependence costs reached a peak of about $350 billion in 1980 and 1981. This study indicates that oil dependence costs reached that level in 2007, soared to approximately $500 billion in 2008, fell back to just over $300 billion in 2009 and remained at that level in 2010. However, U.S. gross domestic product (GDP) today is more than twice what it was in 1980. Relative to GDP, oil dependence costs in 2008 were 3.5%; in 1980 oil dependence costs relative to GDP came to 4.5%. The cumulative, direct costs of oil dependence to the U.S. economy from 2005 to 2010 are estimated to have totaled approximately $2.1 trillion. Monte Carlo simulations reflecting uncertainties in key parameters produced ranges including 90% of the simulation estimates of $429 billion to $602 billion with a mean value of $508 billion for oil dependence costs in 2008 and from $268 billion to $339 billion with a mean of $302 billion for 2010. The uncertainty interval increases with increasing estimated costs. The 5th percentile to 95th percentile range for total costs from 2005 to 2010 is $1.8 trillion to $2.5 trillion.

The GDP losses from 1970 to 2010 estimated by the OSMM are compared below to estimates made using econometric models developed by Hamilton (2005) and Lee, Ni and Ratti (1995). The three methods agree with respect to the order of magnitude of impacts of oil prices on GDP, and the OSMM and Hamilton’s model agree very closely on the GDP impacts of the three largest oil price shocks: 1973-75, 1979-82 and 2003-2010. The methods disagree with respect to the period of relatively low oil prices from 1986 to 1999. The econometric models do not allow potential GDP losses when there is no price shock and do not allow dislocation losses due to a sudden drop in oil prices, whereas the OSMM does. The OSMM uses annual prices and thus filters out short-lived price shocks.
shocks recognized by the econometric models, which are based on quarterly data. In any case, it should not be expected that the oil dependence cost estimates of any of the models would be precise, given substantial uncertainties about key assumptions.

Measuring the costs of oil dependence requires stipulating an alternative, counterfactual case. The logical choice for estimating the excess economic costs due to imperfect competition would be a competitive world oil market, one in which the Organization of Petroleum Exporting Countries (OPEC) cartel had little or no monopoly power. The key question for a retrospective assessment is what the price of oil would have been in a competitive world oil market. The longer the time period under consideration, the more difficult this question is to answer. If the world oil market had not been subject to non-competitive behavior, how much oil would the world have used over the past 40 years? Undoubtedly more than has been consumed. On the one hand, this means that the world’s resources of conventional oil would be even more depleted than they are today. Would technological advances have kept the price of oil from rising as they have for nearly all mineral resources (e.g., Gorelick 2010, ch. 4) or would the more rapid rate of consumption have already driven the world over the “oil peak” (e.g., Deffeyes 2001)? No attempt is made in this paper to answer those questions. Instead, alternative paths for competitive prices are used to test the sensitivity to this assumption, and caution is urged when adding up the costs of oil dependence over long periods of time. The analysis should be most reliable when estimating the costs of oil dependence over a short enough period of time that major changes in the world oil resource base would not be expected to occur.

The costs of oil dependence, estimated as the result of imperfect competition in world oil markets, may appear to be larger than estimates of the external, energy security costs of oil consumption. Parry and Darmstadter’s (2004) review found a range of estimates from $0 to $14/barrel and settled on $5/barrel as their best estimate. Leiby (2007) estimated a range of external costs of oil imports of $6.71 to $13.58 per barrel. Brown and Huntington (2010) estimated a range of externality premiums between $1.10 and $14.35 per barrel. Calculating the external energy security costs of oil consumption has legitimate uses, e.g., if one wanted to know the optimal value of an oil security tax. On the other hand, it will likely underestimate the direct economic costs of oil dependence to the U.S. economy because it excludes wealth transfer costs and losses of potential GDP during periods of relatively stable prices. These costs are a consequence of the use of monopoly power but they are not externalities.

The following section briefly discusses the role of the OPEC cartel and its use of market power to influence world oil prices, using the theory of partial monopoly to illustrate OPEC’s impacts on the world oil market since the 1960s. Section 3 defines oil dependence and the ways in which it harms the U.S. economy. It also briefly reviews the methods used to estimate oil dependence costs in the oil security metrics model and the key assumptions employed in this assessment. Cost estimates for 1970 to 2009 are presented in Section 4, followed by concluding observations.
MONOPOLY POWER AND WORLD OIL PRICES

“The real problem we face over oil dates from after 1970: a strong but clumsy monopoly of mostly Middle Eastern exporters operating as OPEC.” (Adelman 2004)

Figure 1. World Crude Oil Prices, 1930-2009 (2007 $).

a. **Externality or Monopoly?**

The costs of oil dependence to the U.S. economy are the result of a “market failure.” However, oil dependence costs are not an externality. As Professor Adelman has repeatedly pointed out, the problem is monopoly power, that is, the market failure of imperfect competition. Not all market failures are externalities, despite occasional assertions to the contrary (e.g., Zerbe and McCurdy 1999, p. 561). Confusion about this point can lead to incorrect analyses and erroneous policy recommendations.

It is generally accepted that the exercise of market power leads to lower levels of production, higher prices and lower levels of social welfare than could be achieved in a competitive market. The standard prescription for monopoly power is for the government to break up the monopoly into smaller firms, increasing competition. In this case, however, the firms are sovereign states and there is no global antitrust agency with the authority to break them up or force them to privatize their oil resources (Pirog 2007). So what can be done? A great deal, actually. Potential solutions will be taken up below, after the nature of monopoly power and the excess costs it creates have been analyzed.
In a recent analysis of the external costs of energy production and use, an NRC committee correctly judged that neither oil disruption costs nor so-called “monopsony costs” were externalities (NRC 2009, pp. 235-236).\textsuperscript{3} But then, apparently assuming that only externalities are market failures, the Committee incorrectly deduced that the use of monopsony power by the United States would only make matters worse.

“With respect to the issue of monopsony power, it is unquestionable that domestic policy can reduce aggregate demand and lead to a reduction in the world price of oil. Such a policy would generate a transfer in wealth from foreign oil producing nations to the United States. But the ability to exercise monopsony power is not the same as an externality. Externalities create a market failure. Exercising monopsony power creates a market failure where one did not exist before.” (NRC 2009, p. 235; emphasis added)

The erroneous assertion is that no market failure existed previously. There was and is a market failure, however, it is not an externality but rather imperfect competition. Because the OPEC cartel exercises market power in world oil markets (albeit imperfectly) prices are already higher than competitive market levels. By restricting U.S. aggregate demand, the United States is able to lower prices toward the competitive market level and retain some of the monopoly rent that would otherwise go to oil producers. The avoided wealth transfer, \textit{per se}, unambiguously improves the welfare of U.S. consumers.\textsuperscript{4} Whether or not this generates a net welfare benefit to the United States depends on whether the cost of restraining U.S. demand is less or greater than the wealth transfer benefit. To assert that the United States should not take such actions because oil dependence costs are not externalities is a \textit{non sequitur}.

This seemingly esoteric distinction has important policy implications. If the use of monopsony power creates a market failure where one did not exist before, then imposing a tax on petroleum to reduce consumption causes consumer and producer surplus losses but no economic benefits (not considering the use to which the tax revenues might be put). For example, Brown and Huntington (2010) omit the monopsony effect from their estimates of oil import premiums because they do not consider it an externality. But if world oil prices are already elevated above competitive market levels by use of market power, then the surplus losses from reduced U.S. demand will be more than offset by gains in reduced wealth transfer (Hogan and Broadman 1988). Similarly, policies like fuel economy standards that shift the U.S. oil demand curve towards lower consumption cannot claim wealth transfer benefits if the market failure of partial monopoly is denied. Failure to recognize oil dependence as a market failure will lead to under-investing in solutions and eschewing policies that can cost-effectively ameliorate it.

\textbf{b. Measuring Market Power}

OPEC states employ their market power in two ways. In the long-run, they refrain from expanding production capacity even though they possess ample resources and their costs of production are far below market prices. Second, in the short-run they manage output (far from perfectly) via production
quotas, to raise or maintain monopoly prices. Figure 1 shows the dramatic impact that OPEC has had on world oil prices subsequent to the Arab-OPEC oil embargo of 1973-74. Prior to that time the world oil market was arguably also imperfectly competitive but, if so, was clearly managed with a different objective in mind (e.g., Yergen 1992).

Considered as a statistical time series model, world oil prices since 1970 appear to be a random walk (Hamilton 2009). Past history is of no use in predicting the future evolution of a random walk. The best predictor of future oil prices is the current price. Viewed through the lens of the economic theory of partial monopoly, however, a very different picture emerges. A partial monopolist controls a significant share of a market but not the entire market. Its market power (its ability to raise price above the competitive market price, C) is limited by the existence of competitive producers and by the price responsiveness of demand. The economic theory of partial monopoly shows that the price that maximizes the profits of the partial monopolist (\(P_{\text{max}}\)) is a function of its market share (\(\sigma\)), the price elasticity of demand (\(\beta\)) and the price responsiveness of its competitors (\(\mu\)), defined as the number of barrels competitive suppliers would bring to market in response to a one barrel change in supply by the monopolist (von Stackelberg 1952) (equation 1). The greater the price elasticity of demand and the greater the price responsiveness of competitors, the lower the profit maximizing price.

\[
P_{\text{max}} = \frac{C}{1 + \frac{1}{\beta \sigma (\mu + 1)}}
\]

(1)

For given price elasticities of demand and competitive producer supply, OPEC’s profit maximizing price is also a function of its market share.

A critically important characteristic of world oil markets is the fact that price elasticities of oil supply and demand in the short-run (e.g., one year) are approximately an order of magnitude smaller than long-run responses to price changes. For example, in one year, consumers can drive less and take some steps to improve the efficiencies of the vehicles they own but the entire fleet of vehicles cannot be replaced by more technologically advanced vehicles that get twice the miles per gallon. That takes about 15 years. Similarly, energy companies cannot discover, develop, produce and market large quantities of additional oil supplies in a single year. As a consequence, the price that maximizes the OPEC cartel’s profits in the short-run cannot be sustained in the long-run. The long-run profit-maximizing price is much lower. Suranovic (1994) and Wirl (1990) demonstrated that because of the great disparity between short- and long-run price elasticities the profit-maximizing strategy for a partial monopolist such as the OPEC cartel is a series of price shocks, separated by periods of relatively low prices.

World oil prices are plotted against OPEC’s share of the world oil market in Figure 2.5 Upper and lower short-run and long-run profit maximizing price curves are shown, reflecting uncertainties about key parameter values, such as the price elasticities of supply and demand. The parameter values are shown in Table 1. The range of values is consistent with estimates found in the literature.
Table 1. Parameter Assumptions Used in Calculating Long- and Short-run Profit-Maximizing Price Curves for the OPEC Cartel.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High Value</th>
<th>Low Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Oil Demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-run price elasticity</td>
<td>-0.60</td>
<td>-0.45</td>
</tr>
<tr>
<td>Short-run price elasticity</td>
<td>-0.090</td>
<td>-0.068</td>
</tr>
<tr>
<td>Adjustment rate</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Average, 1965-2005</td>
<td>Price per barrel = $36</td>
<td>Million barrels per day = 61.3</td>
</tr>
<tr>
<td>Non-OPEC Oil Supply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-run price elasticity</td>
<td>0.500</td>
<td>0.400</td>
</tr>
<tr>
<td>Short-run price elasticity</td>
<td>0.125</td>
<td>0.080</td>
</tr>
<tr>
<td>Adjustment rate</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>Average, 1965-2005</td>
<td>Price per barrel = $36</td>
<td>Million barrels per day = 36.5</td>
</tr>
</tbody>
</table>

Atkins and Jazayeri (2004) evaluated nine studies of U.S. oil demand over the period 1975-2003 and found mean and median short-run price elasticity estimates of -0.052 and -0.050, respectively, with a range of 0.00 to -0.09. They found mean and median adjustment rates of 0.14 and 0.16 (lagged adjustment coefficients of 0.86 and 0.84), with a range from 0.4 to 0.1. Brown and Huntington (2010) used a value of -0.055 for the United States, taken from a range of published estimates of -0.02 to -0.09. Gately and Huntington (2002) estimated short-run elasticities for OECD countries of -0.05 using a constant elasticity model, and -0.04 for price decreases and -0.08 for price increases using an asymmetric price response model. Their adjustment rates ranged from 0.12 to 0.09. Elasticities for non-OECD countries were smaller: -0.03 for the short-run in the constant elasticity model and +0.04 to -0.05 in the asymmetric model. Adjustment rates ranged from 0.18 to 0.16. Dargay, Gately and Huntington (2007) estimated an asymmetric model with three different effects: (1) price increases exceeding the maximum historical price since 1971 (\( P_{\text{max}} \)), (2) price reductions (\( P_{\text{cut}} \)), and (3) other price increases (\( P_{\text{rec}} \)). For the 30 OECD countries, they found long-run elasticities of -0.55 for \( P_{\text{max}} \), -0.22 for \( P_{\text{cut}} \), and -0.38 for \( P_{\text{rec}} \). Their estimated adjustment rate was 0.07. In countries with rapid income growth they found a much lower long-run price elasticity of -0.18 using a constant elasticity model, and an adjustment rate of 0.18. Hamilton (2009) reviews several studies and concludes that the long-run elasticity of crude oil demand is about -0.2 to -0.3, and that the short-run elasticity is less than -0.1.

Estimates of world oil supply elasticities are less plentiful. Huntington (1991) reviewed studies of the price elasticity of oil supply outside of OPEC and concluded that short-run supply elasticities were considerably less than 0.1. For total non-OPEC supply he estimated an average short-run elasticity of 0.03, and 0.05 for the United States and other OECD countries. For the United States alone, Huntington calculated average elasticities of 0.068 for the short-run and 0.462 for the long-run with an adjustment rate of 0.15. Huntington (1994) chose a long-run elasticity of 0.4 and an adjustment rate of 0.1 for simulation of the world oil market. For the United States, Brown and Huntington (2010) considered a range of short-run elasticities from 0.025 to 0.075. In another simulation analysis, Gately (2004) used a range of 0.15 to 0.58 for non-OPEC long-run supply elasticities, and adjustment rates between 0.80 and 0.91. The parameter values used to construct Figure 2 are shown in Table 1.
A pattern is evident in Figure 2 that does not resemble a random walk. Prior to 1974, while OPEC’s members were nationalizing their oil resources and organizing as a cartel, world prices were well below even the long-run profit maximizing price curve. Following the Arab-OPEC oil embargo late in 1973, prices jumped into the range between the long- and short-run profit maximizing price curves. Again in 1979 with losses of OPEC supplies due to the Iran-Iraq war, prices again shot upward. At this point, OPEC and especially Saudi Arabia decided to defend the high price of oil. OPEC’s 1980 production was 4 million barrels per day lower than its 1979 production due to losses from Iran and Iraq (EIA 2009, table 11.5). OPEC production fell by another 4 million barrels per day in 1981 only half of which was due to Iran and Iraq. From 1982 to 1985 production from Iran and Iraq increased but overall OPEC production was cut by 6 million barrels per day. In 1981 Saudi Arabia produced 9.8 million barrels per day. In 1985 Saudi Arabia produced only 3.4 million barrels per day. Total OPEC output was only a little more than half of the 1979 level. It is not possible to reconcile this pattern of behavior, i.e., cutting back supply when prices double while holding vast reserves that could be produced at far below prevailing prices, with the behavior of competitive producers. It fits perfectly, on the other hand, within von Stackelberg’s partial monopoly theory.

With little room for further production cuts, OPEC increased output by 2 million barrels per day in 1986. World oil prices collapsed, but to the long-run monopoly price level rather than to the levels seen...
before the first oil price shock. Only in 1998 did prices dip much below the long-run profit-maximizing level.

With three quarters of the world’s proven reserves and more than half of the ultimately recoverable resources of conventional oil, it was only a matter of time before OPEC regained market share and market power in a growing world market (Greene, Jones and Leiby, 1998). And so, when world demand for oil increased after 2003, OPEC did not respond to growing world oil demand with increased production but instead allowed prices to rise. In 2008, prices reached the short-run profit maximizing level, once again contributing to a global recession.

**MEASURING THE COSTS OF OIL DEPENDENCE**

Oil dependence harms the U.S. economy in three ways: (1) transfer of wealth in the form of monopoly rents to oil exporters, (2) loss of GDP due to the higher monopoly price of oil, and (3) dislocation losses due to oil price shocks. The three components of the costs of oil dependence are distinct and do not overlap. There are other important costs of oil use that are not measured here. These include strategic, military and political costs, as well as environmental externalities such as greenhouse gas emissions, other pollutants produced by the combustion of petroleum and pollution due to oil spills and leakage (e.g., see Delucchi and Murphy, 2008).

Wealth transfer is the most straightforward quantity to measure. It is the product of total U.S. oil imports and the difference between the actual market price of oil (influenced by market power) and what the price would have been in a competitive market. Wealth transfer is illustrated in Figure 3, which shows national oil supply and demand curves for the United States. The curves do not intersect at either the hypothetical competitive market price \( P_0 \) or the actual market price \( P_1 \), so the United States imports oil. At the higher price level, the United States produces \( S \) \( Q_1 \) and demands \( D \) \( Q_1 \) and so imports the difference \( (D \) \( Q_1 - S \) \( Q_1 \)). The transfer of wealth from U.S. consumers to foreign oil producers is the amount represented by the rectangle: \( (P_1 - P_0)(D \) \( Q_1 - S \) \( Q_1 \)).

![Figure 3. Diagrammatic Representation of Wealth Transfer and Potential GDP Losses.](image-url)
The transfer of wealth is not an economic loss to the world economy but it is a loss to the U.S. economy. Depending on world trade patterns, the wealth transfer could lead to a small increase, small decrease or, very likely, no significant change in U.S. GDP. For example, an oil exporter could purchase farmland in Iowa with the monopoly rent gained by selling oil to U.S. consumers. If the same amount of produce were grown on the land as the year before, there would be no impact on U.S. GDP. The difference would be that U.S. citizens no longer owned the land or the produce. The oil exporter is richer, U.S. citizens are poorer. This is an unambiguous loss to the U.S. economy that is not included in measured changes in U.S. GDP (e.g., Huntington and Eschbach 1987).

Estimates of what world oil prices would have been in a competitive market can be obtained from three sources: (1) world oil market models, (2) the lowest prices observed in the historical market, and (3) direct estimates of the cost of finding, producing and delivering oil from various regions. All of these sources have shortcomings. World oil market models are imperfect. Because of the very low short-run elasticities of world oil supply and demand, market prices may temporarily fall below competitive market levels even in the presence of market power. Costs of finding, producing and delivering oil are specific to oil occurrences and are not market prices. Nonetheless, these data provide useful indicators of what a competitive market price of oil would have been.

Estimates of hypothetical competitive world oil prices from five published studies were surveyed by Greene and Leiby (2006). The estimates ranged from a low of $8.50 to a high of $15.10. Considering the historic record, the price of oil was $12.80 in 1972 before the first oil price shock, and the lowest annual average price since then was $15.00 per barrel in 1998. Estimates of the costs of oil supply by the International Energy Agency (IEA 2001) ranged from $5 per barrel in the Middle East to $13.20 for major international oil companies. The International Energy Agency (IEA) updated its global long-term oil-supply cost curve based on a field-by-field analysis of world oil resources. The curve represents supply cost as a function of cumulative global production (IEA 2008, figure 9.10). Approximately 1.1 trillion barrels have already been produced at costs ranging from $5 to $30 per barrel, of which 80% was produced since 1974 (BP 2010). In the Middle East and North Africa alone, well over a trillion barrels are estimated to remain, with supply costs ranging from under $10 to about $25 per barrel. Adding the rest of the world increases estimated remaining supplies to 2.1 trillion, with the rest-of-world increment having supply costs ranging from $10 to $40 per barrel. A competitive market would have selected the lowest cost sources of supply to produce the 0.9 trillion barrels supplied since 1973 from the 3.2 trillion barrels of available resources.

Estimates of lifting and finding costs for major U.S.-based oil and natural gas producers are calculated annually by the U.S. Energy Information Administration (USDOE/EIA 2011). These costs include all production costs except transportation. The costs are strongly influenced by current and anticipated crude oil prices in two ways: (1) higher prices encourage exploration and drilling in more difficult environments where major finds are less likely, and (2) higher oil prices raise the cost of acquiring access to land on which to drill. As a result, from 1986 to 2001 finding costs are generally below $10/bbl (2009 $) for domestic onshore and foreign operations, while offshore costs are a few dollars per barrel higher (USDOE/EIA 2011, figure 17). Finding costs jump after 2003, to over $60/bbl for offshore operations and just over $20/bbl for U.S. onshore and foreign operations. Lifting costs are
much less sensitive to oil market conditions. Prior to 1991, lifting costs per barrel of oil equivalent ranged from $5/bbl to $9/bbl, were below $5/bbl from 1995 to 2004, and peaked at almost $10/bbl for domestic operations in 2008. If one takes the low cost decade of the 1990s as indicative of competitive market conditions, finding plus lifting costs for major U.S. oil producers would be about $12-$14/bbl. If $2/bbl is added for transportation costs, and 10% for profit, $16.50 would be a reasonable estimate of a competitive market marginal cost for these producers.

In estimating the costs of oil dependence, historical prices are used to represent competitive market prices until 1974. The reference price path sets the 1974 the hypothetical competitive market price at $14.40 per barrel, and increases by $0.10 per year to reach $18 per barrel in 2010. High and low oil price assumptions for sensitivity analysis lead to oil prices of $25.20/bbl and $15/bbl in 2010, respectively.

Potential GDP losses result because a basic resource used by the economy to produce output has become more expensive. As a consequence, with the same endowment of labor, capital, and other resources, our economy cannot produce quite as much as it could have at a lower oil price. The loss of potential GDP can be well approximated by the producers’ and consumers’ surplus losses in the oil market (Sugden and Williams 1980, ch. 10). These are represented in Figure 3 by the triangles under the oil supply and demand curves. A key issue in the estimation of consumer and producer surplus losses is the dynamic nature of both markets. The dynamic response of supply and demand implies that the loss due to a step increase in the price of oil will increase over time. Similarly, the effect of a sudden increase in price followed by a sudden decline will be muted. Finally, a decrease in the price of oil, even a sudden decrease, will increase GDP, reducing the costs of oil dependence. Potential GDP losses are also measured relative to the hypothetical competitive world oil price. The method for estimating surplus losses for dynamically adjusting supply and demand is explained in Greene and Leiby (2006).

Dislocation costs are undoubtedly the most complex and difficult to measure, chiefly because they occur at a fairly detailed economic level and because they often depend on the perceptions of economic agents. Over the years analyses of oil price shock impacts on GDP have employed increasingly sophisticated measures of oil price shocks that emphasize direction and surprise as well as the size of the increase. In particular, minor or gradual movements in oil prices are unlikely to induce shock effects, while large, sudden, unexpected movements have larger impacts than might be expected based on oil costs relative to GDP (e.g., Gronwald 2008). In the estimates presented below, an oil price shock is defined as a change in the price of oil from the previous year that exceeds 5%. Dislocation losses are not measured relative to the hypothetical competitive world oil price but relative to a price level to which the economy has adjusted, given the historical price trajectory. Let $P_t$ be the current world oil price, $p_t$, be the price to which the economy has adjusted, and $\lambda$ be the adjustment rate. The “adjusted price” in year $t$ is then the following.

$$ p_t = \lambda P_t + (1 - \lambda)p_{t-1} $$

The literature of energy economics contains a number of studies estimating the impacts of oil price shocks on GDP derived by statistical inferences from historical time series data (e.g., see Hamilton 2005;
Jones, Leiby and Paik 2004; Hickman 1987). These statistical estimates include both the potential GDP and dislocation loss effects. Based on Hickman’s simulations of the impact of a 50% increase in oil prices in 1983, in which he tested 14 different macroeconomic models, Greene and Leiby (2006) selected an average oil price elasticity of GDP of -0.055. In the first two years of the price shock Greene and Leiby estimated that 75% of the total GDP losses were dislocation losses. This leads to a dislocation loss elasticity of -0.04 for the year 1983. This is similar to Brown and Huntington’s (2010) midpoint estimate of -0.044 within a range of -0.012 to -0.078.

Both intuition and economic theory suggest that the relative impacts of oil prices on GDP should vary in proportion to oil’s value share of total output (e.g., Huntington 2005, p. 43). This is the case for the potential GDP loss measure described above. Nevertheless, recent studies using oil price shock measures intended to reflect large, unanticipated price changes indicate that the impacts of oil price shocks on U.S. GDP have not diminished over time (e.g., Naccache 2010). The method used in this study sides with theory and assumes that the sensitivity of the economy to oil price shocks varies with the oil cost share of GDP. Since the oil intensity of GDP today is only about half what it was in 1980, the method used here implies that the economy is substantially less sensitive to oil price shocks today than it was in the 1980s. The equation for estimating dislocation losses is shown below, in which λ is the fraction of maximum losses incurred in the year the shock occurs, φ is the oil value share of GDP, and ABS is the absolute value function. P and pt are as defined in equation 2.

\[
DL_t = \lambda \left\{ \text{ABS} \left( 1 - \frac{P_t}{p_t} \right)^{0.04 \left( \frac{\phi_t}{\phi_{t-1}} \right)} \text{GDP} \right\} + (1 - \lambda) \left\{ \text{ABS} \left( 1 - \frac{P_{t-1}}{p_{t-1}} \right)^{0.04 \left( \frac{\phi_{t-1}}{\phi_{t-1}} \right)} \text{GDP}_{t-1} \right\}
\]

**A COMPARISON WITH ECONOMETRIC MODELS**

Dislocation losses due to oil price shocks are perhaps the most difficult to measure of the three components of the cost of oil dependence. The impacts of price shocks via dislocation losses depend on highly subjective factors such as expectations and public policies as well as more objective factors such as the quantity of oil use and the structure of the economy. Prior to the 1970’s, the concept of “oil price shocks” was essentially non-existent in the United States. For most of its history, the United States was a net petroleum exporter. During the 1970’s though, the United States saw an increasing dependence on imported oil. The 1973 and 1979 oil crises apparently caused substantial detrimental economic impacts. Noting that 9 out of the 10 recessions in the post-World War 2 era were preceded by oil price increases (Hamilton 2005), economists have since made numerous attempts to estimate the oil price-GDP relationship through econometric models.

Beginning in the 1980’s, studies began to appear proposing various methods of measuring the impacts of oil shocks on the economy. Early models, such as that proposed in Hamilton (1983) and Burbidge and Harrison (1984), were constructed using historical data that contained relatively short-lived oil price increases preceded and followed by relatively stable prices. These models were typically
symmetric in that the models implied that the impacts of oil price decreases would be the same as the impact of price increases, and the models were usually linear in nature.

Following the collapse of the oil market in 1985, the oil-price macroeconomy relationship seemed to collapse as well. Models estimated using data prior to the collapse no longer held up and subsequent studies attempted to remedy this issue. Proposed solutions included separately treating price increases and decreases (Mork 1989) and various non-linear models. However, Hooker (1996) noted that neither of these hypotheses were supported by the data. Rather, he suggested that oil price volatility could potentially be responsible for the collapse of previously-estimated oil price-macroeconomy relationships. That is, in periods of volatile oil prices, a sudden increase would not be perceived as a surprise and therefore not a shock. As a result, more recent models such as Lee, Ni and Ratti (1995) and Hamilton (2003) constructed oil variables that attempt to take oil price volatility into account by distinguishing oil price shocks from typical oil price behavior.

Given the difficulty of measuring the dislocation costs of oil price shocks, it is useful to compare the OSMM’s estimates to those of well-known models. For this purpose, we replicated the results from the vector autoregressive (VAR) model proposed by Hamilton (2003) and updated in Hamilton (2005), as well as a modified regression model utilizing the oil price variable proposed by Lee, Ni and Ratti (1995). Several other models were considered including those by Jiminez-Rodriguez and Sanchez (2004), Killian (2008) and Lescaroux (2011). Some of these other statistical models correlated GDP growth with lagged values of GDP, and current and lagged values of oil price; while others focused on other variables such as interest rates and/or industry-level output.

Hamilton (1983) was one of the first to propose a model to measure the macroeconomic impacts of oil price shocks and the seminal nature of his work contributed to our selecting his recent model for comparison to the OSMM. In addition, his measure of a price shock, that being whether there has been a net oil price increase over the last three years (NOPI3), provides a basic means of attempting to account for the nature of human behavior in reacting to oil prices. It does so by assuming that increases in oil price that have been seen in the past three years do not “surprise” the market and thus do not cause a price shock. In addition, all of the information (including data and methodology) needed to replicate the predictions of Hamilton’s model, were available through either the paper itself or external files provided publically by the author. Lee, Ni and Ratti’s (1995) oil price shock variable, , reflects market anticipation of price behavior as well as conditional variance. This variable provides yet another significantly different method of measuring oil shocks that focuses not only on the size of the shock but also on the price history and stability surrounding the event.

There are three key differences between the OSMM and Hamilton’s VAR model. First, Hamilton used a quarterly producer price index for crude oil based on the end-of-the-month value for each quarter, while the OSMM uses an annual refiner’s acquisition cost per barrel. As a consequence, Hamilton’s model may “see” short-lived oil price shocks that are “averaged out” in the OSMM’s annual data. The manner in which the models measure GDP impacts is also different. The OSMM independently estimates potential GDP losses and dislocation losses and therefore allows these two measures to move in opposite directions when there is an oil price decrease. In Hamilton’s model oil
price decreases have no impact. Finally, the potential GDP costs estimated by the OSMM are measured relative to a hypothetical competitive market, and the price shock costs are measured relative to an estimated price to which the economy has adjusted. This latter price is calculated as a weighted average of past oil prices.

**a. Methodology Used for Model Comparison**

Hamilton’s NOP3 model was reproduced using information provided by Hamilton (2003) and Hamilton (2005) as well as data and calculations provided by Hamilton online. The GDP growth rate for Hamilton’s model is calculated by the following:

\[
y_t = GDP \text{ Growth Rate}_t = 100 \times \ln(GDP_t / GDP_{t-1})
\]

(4)

A net oil price increase over the last three years (NOPI3) is found through the following series of equations where \(P\) is the producer price index for oil for each quarter, at the end of the month in that quarter:

\[
\log_{ratio}_t = 100 \times \ln\left(\frac{P_t}{P_{t-1}}\right)
\]

(5)

\[
Cumul_t = Cumul_{t-1} + \log_{ratio}_t
\]

(6)

\[
Nominal \text{ Crude Oil Price Growth Rate} = e^{Cumul_t}
\]

(7)

A maximum over the previous three years is calculated for each time period. The rate of change is calculated using this equation:

\[
\delta_t^{*} = \frac{Nominal \text{ Crude Oil Price Growth Rate}_t}{three \text{ year max}_{t-1}}
\]

(8)

If the above value is equal to or less than 0, the value is considered to be 0.
The lagged values are inputted into the equation,

\[ y_t = 0.87 + 0.24y_{t-1} + 0.11y_{t-2} - 0.08y_{t-3} - 0.13y_{t-4} - 0.009o_{t-1}^* - 0.014o_{t-2}^* \\
- 0.009o_{t-3}^* - 0.031o_{t-4}^* \]

(9)

to estimate predicted GDP growth rates. A second equation without the \( o^* \) variables is used to predict GDP growth rates, \( y^* \), in the absence of oil price shocks. The impact of the oil price shock on quarterly GDP growth rates is calculated by the following equation.

\[ \Delta_t = \frac{y_t}{e^{100}} - \frac{y_t^*}{e^{100}} \]

(10)

Estimates of GDP impacts were also generated using modified version of Hamilton’s model based on Lee, Ni and Ratti’s oil shock variable. The variable attempts to represent the surprise factor by scaling oil price changes by dividing by a measure of the recent variability of oil prices.\(^{10}\) The intuition is that a given oil price change will have a smaller impact when prices have recently been volatile than when they have been relatively constant.

All three measures are attempting to measure both potential GDP losses and dislocation losses; wealth transfer is not included in the OSMM estimates shown in Figure 4. Estimates from Hamilton’s model and the OSMM agree very closely for the three major oil price shocks of 1973-75, 1979-82 and 2003-2010. Using the alternative oil variable as proposed by Lee, Ni and Ratti results in a considerable increase in the estimated annual GDP impacts during most of oil price shock periods. During unshocked periods, the econometric models estimate no GDP impacts at all, while the OSMM still sees potential GDP losses because of the difference between the actual price of oil and the hypothetical competitive market price. Another difference arises from the fact that the OSMM is based on annual price and GDP data while the econometric models are based on quarterly data. These models see price shocks during the 1990s where the OSMM does not. Finally, the OSMM estimates that GDP losses remained high after the price shock of 1979-82 had ended, due to the persistence of much higher than competitive market prices. The crash of oil prices in 1986 does not reduce GDP losses predicted by the OSMM because gains in potential GDP are offset by dislocation costs. Interestingly, Lee, Ni and Ratti’s (1995) price variable also shows a loss of GDP associated with the oil price collapse.
Figure 4. Annual GDP impacts estimated by three models.

Comparing the models’ estimates in terms of percent of GDP shows similar patterns.

Figure 5. Impacts as a percentage of GDP, as estimated by three models.

b. Differences in GDP Impacts

While the methodologies for estimating the economic impacts of changes in oil price differ significantly across the three models, a comparison of results indicates that the OSMM is of the same
general magnitude as estimates of the other two models, especially during the notable historical oil price events. When considering overall impacts from the time span from 1971:I-2010:IV, Hamilton’s model indicated a total GDP cost of 2,181 billion dollars while the OSMM indicates 2,947 billion dollars. Hamilton’s model utilizing Lee, Ni and Ratti’s oil variable indicated a 2,776 billion dollar loss over a shorter time period from 1971:1-2002:II.11

The economic impacts measured by the OSMM and Hamilton’s VAR model during the 1973 and 1979 oil crises along with the time period beginning in 2004 are similar in magnitude as indicated in Table 2 as well as in shape as seen in Figures 4 and 5. While Lee, Ni and Ratti’s variable in Hamilton’s model indicate much larger impacts, during the two periods that data was available for calculating impacts, GDP costs are still well within reason.12

<table>
<thead>
<tr>
<th></th>
<th>Hamilton</th>
<th>OSMM</th>
<th>Lee, Ni and Ratti</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973-1975</td>
<td>$199 billion</td>
<td>$200 billion</td>
<td>$392 billion</td>
</tr>
<tr>
<td>1979-1982</td>
<td>$350 billion</td>
<td>$520 billion</td>
<td>$475 billion</td>
</tr>
<tr>
<td>2004-2009</td>
<td>$1019 billion</td>
<td>$828 billion</td>
<td>Data not available</td>
</tr>
</tbody>
</table>

Figure 6. Comparison of OSMM and Hamilton’s estimates for the period 1971-2010; and of Hamilton’s model against Lee, Ni and Ratti’s variable implemented in Hamilton’s model for the period 1971-2002.
However, several differences in the resulting GDP impacts estimated in the models are also noted. Hamilton’s model regards the impacts of decreases in oil price as insignificant, and attributes this to the dislocation costs resulting from the economy attempting to shift to the new price being mitigated by increased production associated with a decrease in oil price. Also, because Hamilton’s model is calibrated using end-of-month quarterly data, it sees oil price shocks that are significantly diminished or cannot be seen at all in annual data. Thus, some impacts of short-lived shocks are predicted by Hamilton’s model (e.g., 1990-91) but are filtered-out in the annual data. Differences between the annual Refiners’ Acquisition Cost prices and the quarterly PPI data are shown in Figure 7.

![Fig. 7: Comparison of Oil Price Series](image)

Figure 7. A comparison of the two oil price data sets.

These small quarterly shocks account for the two events occurring between 1986 and 1998 using Hamilton’s NOPI3 variable and are magnified when Lee, Ni and Ratti’s variable is used. The impacts seen from 1998-2002 are significantly larger in both variations of Hamilton’s model. Again, this result is largely due to the quarterly data reflecting a far more significant oil price increase than annual data, although the OSMM estimates a relatively minor increase in GDP impacts as a result of a similarly minor increase in annual price. However, during the significant oil price events in 1973, 1979 and after 2003, the OSMM and both variations of Hamilton’s VAR model estimate similar macroeconomic impacts over approximately the same time period.
In 2008, the U.S. economy suffered the greatest losses in history due to oil dependence. According to estimates made using the OSMM and the parameter assumptions in Table 1, the combined costs of wealth transfer and GDP losses amounted to approximately half a trillion dollars (Figure 4). The largest component was wealth transfer at $300 billion. Dislocation losses were next at approximately $150 billion, followed by potential GDP losses amounting to $80 billion. In 2009, the average oil price fell to just under $60 per barrel and rebounded to nearly $75 per barrel in 2010; oil dependence costs were roughly $330 billion in both years.

![Costs of Oil Dependence to the U.S. Economy: 1970-2010](image)

Figure 8. Estimated Costs of Oil Dependence to the U.S. Economy: 1970-2010.

It is not appropriate to add the costs of oil dependence over a long period of time, as noted above. Had the world oil market operated as a competitive market for the past 40 years, it would be in a different state today. However, it is not unreasonable to add annual costs over a few years. Adding cost for 2005-2010 yields a total economic loss to the U.S. economy of $2.1 trillion over the six-year period.

Although oil dependence costs reached their highest level in 2008, 1980 is still the highpoint for costs relative to the size of the economy. Compared to GDP, oil dependence costs were almost 4.5% in 1980 but were just under 3.5% in 2008 (Figure 5). These comparisons include wealth transfer costs which are not GDP losses. In terms of lost GDP, 1980 remains the worst year at 2.5% with 1974 not far behind. The Oil Price shock of 2008 cost the economy about 1.5% of GDP. The decade between 1990 and 2002 is labeled “oil independence” because the total costs of oil dependence never exceeded 1% of GDP and GDP losses were usually below 0.5%. During this period, oil supplies seemed abundant and OPEC appeared to have little market power.
None of the key parameters that determine the costs of oil dependence is known with certainty. For this reason a sensitivity analysis was carried out, in which ranges of the parameters shown in Table 2 were used to define triangular probability distributions. The results of one thousand iterations are displayed in Figure 10. A ninety percent uncertainty interval can be as large as +/-25% during the periods when costs are greatest. Nonetheless, there is no doubt that the costs of oil dependence are substantial: $150 to $250 billion for the year 1975, $250 to $350 billion in 1980 and $400 to $600 billion in 2008.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference</th>
<th>High</th>
<th>Low</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Price Elasticity of GDP in 1983-6</td>
<td>-0.055</td>
<td>-0.09</td>
<td>-0.02</td>
<td>Decreases over time in proportion to oil cost share of GDP.</td>
</tr>
<tr>
<td>Share of GDP elasticity due to disruption costs</td>
<td>75%</td>
<td>90%</td>
<td>60%</td>
<td>Determines size of dislocation or price shock losses.</td>
</tr>
<tr>
<td>Reduction of first year price impact on GDP</td>
<td>50%</td>
<td>1/3</td>
<td>2/3</td>
<td>Most studies indicate that full impact is not felt until the year after a price shock.</td>
</tr>
<tr>
<td>Dislocation costs adjustment rate</td>
<td>0.333</td>
<td>0.444</td>
<td>0.222</td>
<td>A larger number implies a faster recovery from a price shock.</td>
</tr>
<tr>
<td>U.S. &amp; ROW price elasticity of oil demand</td>
<td>-0.079/-0.53</td>
<td>-0.09/-0.60</td>
<td>-0.068/-0.45</td>
<td>Short-run/Long-run; adjustment rate of 0.15; at average 1965-2005 price of $36/bbl., 61.3 mmbd.</td>
</tr>
<tr>
<td>U.S. &amp; ROW price elasticities of oil supply</td>
<td>0.06/0.40</td>
<td>0.08/0.53</td>
<td>0.04/0.27</td>
<td>Short-run/Long-run; adjustment rates of: 0.25, 0.225, 0.2, at average 1965-2005 price of $36/bbl., 36.5 mmbd.</td>
</tr>
<tr>
<td>Competitive market world oil price in 1970</td>
<td>$13</td>
<td>$14</td>
<td>$12</td>
<td>Based on literature review of model simulations, recent historical prices and finding and lifting costs.</td>
</tr>
<tr>
<td>Annual increase in competitive market price 1970-2010</td>
<td>$0.15</td>
<td>$0.30</td>
<td>$0.0</td>
<td>Over 40 years a drift of $0.15/yr raises the reference competitive price of oil to $19/bbl.</td>
</tr>
</tbody>
</table>
CONCLUDING OBSERVATIONS

The costs of oil dependence are a result of non-competitive behavior in the world oil market and resulting higher than competitive prices and related oil price shocks, combined with high levels of oil use and oil imports, plus the lack of adequate, economical substitutes for petroleum. The costs to the U.S. economy have been and remain very large. Oil dependence costs reached approximately $500 billion in 2008 and totaled approximately $2.1 trillion over the last six years. Wealth transfer costs, which are not included in many assessments of the costs of oil dependence, are an increasing share of total oil dependence costs. Wealth transfer costs are a real cost to the U.S. economy if the relevant market failure is recognized as the monopoly influence of the OPEC cartel in world oil markets. The estimates presented in this paper are not intended to be precise but are intended to more likely underestimate than overestimate costs. A sensitivity analysis suggests that a reasonable confidence bound for the estimates is +/- 25%.

The large-scale behavior of the world oil market since 1970 fits well within the theory of partial monopoly. Recognizing the very large differences between the short-run (one year or less) and long-run responsiveness to price is critical to understanding the volatility of oil prices over the past forty years. In this context, the OPEC cartel has two methods of influencing world oil prices. In the long-run, they influence prices by not expanding their productive capacity despite holding vast resources that could be produced at far below prevailing market prices. In the short-run production is imperfectly controlled by negotiated production quotas. There is no doubt that OPEC’s influence on the world oil market has by no means been perfectly coordinated. This is why oil prices over the past 40 years are statistically
indistinguishable from a random walk. At the same time, intermittent price shocks have been shown to be a profit maximizing strategy for a cartel in a market with greatly different long- and short-run price elasticities. In the final analysis, exercise of monopoly power by the OPEC cartel has been enormously profitable for its members and very expensive for oil dependent economies like the United States.

A comparison of the impacts of oil prices on GDP estimated using the OSMM were compared with estimates made using econometric models estimated by Hamilton (2005) and Lee, Ni and Ratti (1995). Considering only the three largest price shocks, 1973-75, 1979-82 and 2003-10, estimates by the OSMM agree closely with those of Hamilton’s model. Estimates made using Lee et al.’s model are substantially larger. Estimates of total impacts on GDP for the entire period available show agreement within +/- 25%. This is not unreasonable given the inherent uncertainties in such estimates and is sufficient to establish the approximate magnitude of GDP impacts. These estimates do not include wealth transfer costs, which are additive to GDP impacts.

How much of the cost of oil dependence can be avoided? History suggests that reduced demand and increased non-OPEC supply, such as seen between 1990 and 2002, could reduce oil dependence costs by an order of magnitude. A comprehensive strategy of efficiency improvement, substitution of other energy sources for petroleum and increased domestic energy production could do the same in the future (Greene 2010).
References


APPENDIX

CALCULATION OF OPEC’S SHORT- AND LONG-RUN

PROFIT MAXIMIZING PRICE CURVES

The derivation begins with the profit maximizing price equation for a partial monopolist facing a group of competitive producers (von Stackelberg 1952).

\[
P_{\text{max}} = \frac{C}{1 + \left(1 + \frac{1}{\beta} \sigma(\mu + 1)\right)}
\]

(A.1)

In equation A.1, \(\beta\) is the price elasticity of world oil demand, \(\sigma\) is the monopolistic cartel’s share of the world oil market and \(\mu\) is the rest of world (ROW) supply response.

Following the derivation of Greene (1991) the ROW supply response, \(\mu = \frac{dq_R}{dq_O}\), can be expressed as a function of the supply elasticity of ROW producers, the world price elasticity of demand, and the ROW market share \((1-\sigma)\).

\[
\mu = \frac{dq_R}{dq_O} = \frac{dq_R}{dq_O} \frac{P}{q_R} \frac{dq_R}{P} = \frac{dq_R}{dq_O} \frac{1 + \frac{dq_R}{dq_O}}{1 - \frac{\alpha}{\beta} (1 - \sigma)}
\]

(A.2)

If linear supply and demand equations are assumed, the ROW supply response can be expressed as a function of the price slopes of ROW supply, \(a\), and world demand, \(B\).

\[
\mu = \frac{dq_R}{dq_O} = \frac{\alpha}{B} \frac{q_R}{q_R} (1 - \sigma) = \frac{\alpha}{B} \frac{1 - \frac{\alpha}{B} (1 - \sigma)}{1 - \frac{\alpha}{B}}
\]

(A.3)

The simplification is achieved by the substitution, \(Q/q_R = 1/(1-\sigma)\).

Before substituting the linear model expression for \(\mu\) into the equation for OPEC’s profit maximizing monopoly price, it must be converted to linear model form also.
\[
\frac{P_{max}}{1 + \frac{1}{B} \sigma(\mu + 1)} = \frac{C}{1 + \frac{1}{B} \frac{P_{max}}{Q} \sigma(\mu + 1)} = C - \frac{Q}{B} \sigma(\mu + 1)
\]

(A.4)

If it is further assumed that the slope of the linear demand equation increases in proportion to exogenous (not price induced) demand growth, then equation A.4 becomes a function of the initial year price slope and initial year demand.

\[
P_{max,t} = C - \frac{Q_t}{B_o} \frac{Q_{t+1}}{Q_o} \sigma(\mu + 1) = C - \frac{Q_o}{B_o} \sigma(\mu + 1)
\]

(A.5)

The short-run version of equation A.3 differs from the long-run version only in that the short-run price slopes (\(\lambda_A\) and \(\lambda_B\)) are inserted in place of the long-run price slopes (\(a\) and \(B\)).

Oil prices and production data from the BP Statistical Review of World Energy, June 2009. Elasticities are similar to values estimated by Dargay and Gately (2010) and consensus values chosen by Brown and Huntington (2010).
END NOTES

1 The term “market failure” is unfortunate because it implies an inability to perform a function. In welfare economics that function is the absolute maximization of social welfare, in the Pareto sense. The full accomplishment of that task is almost certainly never accomplished by any market. Thus, as Zerbe and McCurdy (1999) note, market failure is ubiquitous. The relevant questions, of course, are, how serious is the shortcoming and can it be corrected?

2 Indeed, not only are not all market failures externalities but not all externalities are market failures, which is the case for pecuniary externalities.

3 The monopsony cost of oil is defined as the reduction in the total cost of oil that the United States could realize by reducing its demand for oil. Because the United States is the world’s largest oil consumer and accounts for approximately one fourth of world demand, it possesses monopsony power, analogous to OPEC’s monopoly power. Individual U.S. consumers do not have monopsony power, which requires coordinated action on the part of the United States, such as implementing fuel economy standards.

4 The use of market power is inherently an adversarial, negative sum game. This paper takes the perspective of the oil consuming nation.

5 The mathematical derivation of short- and long-run profit-maximizing prices as a function of market share and elasticities is provided as an appendix to this paper.

6 It probably goes without saying that decreasing production in response to an enormous increase in price is opposite to the behavior of a competitive supplier. Several econometric studies have confirmed the rather obvious inference that OPEC does not behave as a competitive oil producer. Still, there remains a great deal of room for argument about what kind of cartel OPEC is and how effective and efficiently they maximize their profits.

7 A great deal of confusion over what to do about oil dependence arises from disagreement about the nature of oil dependence. Some equate oil dependence with the quantity of oil imported or the share of domestic consumption that is imported. However, these are only pieces of the problem. Oil dependence is a combination of factors: (1) a non-competitive world oil market strongly influenced by the OPEC cartel, (2) the high levels of U.S. imports, (3) the importance of oil to the U.S. economy, and (4) the lack of economical and readily available substitutes for oil.

8 While these are average costs for all firms, they are average costs for additions to proved reserves in each year and thus represent increments to supply at the current margin. Furthermore, especially in years when oil prices are high, the costs include exploration and development of resources that would not be exploited in a competitive oil market in which production from low-cost suppliers would be greatly increased.

9 Data available at: http://dss.ucsd.edu/~jhamilto/nonlin.zip

10 For details, see Lee et al., 1995.

11 All dollar values are in chained 2005 dollars unless noted otherwise.

12 We would like to thank Jim Hamilton, Shawn Ni and Francois Lescaroux for their valuable comments and advice on this section of the paper. Any errors are the authors’ responsibility.

13 The model variation using Lee, Ni and Ratti’s variable was only replicated to 2001 based on data provided by Jim Hamilton.

14 Files used in recreating Hamilton’s OLS regression with both NOPI3 and Lee et al.’s oil variables along with the OSMM available upon request.

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