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Reconciling Methods for Measuring U.S. Oil Dependence Costs

Charles Sims, PhD
Faculty Fellow, Howard H. Baker Jr. Center for Public Policy
Assistant Professor, Department of Economics
University of Tennessee

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Reconciling Methods For Measuring U.S. Oil Dependence Costs

EXECUTIVE SUMMARY

The cost of the United States' dependence on foreign sources of oil has been an argument for government intervention in energy markets for nearly half a century. The costs of oil dependence refers to the loss of economic welfare that may arise from the U.S. consuming too much oil from foreign sources. The loss of economic welfare could reflect environmental costs of oil consumption or losses that accrue to the United States from a non-competitive world oil markets. However, about 24% of the oil consumed in the United States in 2016 came from foreign countries, the lowest level since 1970. This led many analysts to assert that costs of oil dependence are waning. If the costs of oil dependence are indeed waning, this would call into question a variety of energy policies including oil import quotas and tariffs and subsidies for domestic oil producers.

However, declining oil dependence cost measures are difficult to quantify due to the lack of a definitive measure of U.S. oil dependence costs. While oil dependence typically refers to the percentage of domestic oil consumption that is imported, the literature calculates the cost of this oil dependence in a variety of ways. Existing oil dependence cost estimates include some or all of the following: imperfect competition, vulnerability to supply shocks, environmental externalities, national security spending to maintain oil supplies, and the implications for new technology adoption that arise from oil's dominant role as an energy source. Some of these costs are focused only on foreign oil imports while others include the costs of foreign and domestic oil consumption. Further complications arise as some analysts focus only on the external costs not captured by world oil markets. For example, the term oil premium focuses on the extent to which the costs to the United States as a whole from extra oil consumption may exceed the private costs to individual users. Understanding the conceptual differences between oil dependence cost measures will become critical as a changing energy landscape prompts the United States to reevaluate its energy policy.

After reviewing the literature on the costs of oil dependence, we conclude that virtually all oil dependence cost estimates are motivated by world oil market failures. Thus, the vast majority of oil dependence costs would be more accurately defined as the costs that arise when prices are an imperfect signal of the true cost of imported oil. However, existing oil dependence cost estimates differ in six specific dimensions:

1. *What market failures are considered?* Existing oil dependence cost estimates include some or all of the following: (1) potential GDP losses, (2) wealth transfer from U.S. to foreign producers due to monopolistic pricing, (3) disruption costs, (4) military security costs, (5) the cost of maintaining the strategic petroleum reserve, (6) the environmental externalities associated with oil production and consumption and (7) the political consequences of oil wealth. Each of these potential costs can be directly or indirectly linked to a market failure in the world oil market or, in the case of disruption costs, in associated capital and labor markets. However, some of these cost components (particularly 4, 6, and 7) are routinely omitted from oil dependence costs estimates due to the difficulty in measuring these costs. There is also an ongoing debate surrounding the existence of market power on the supply side in world oil markets. Those analysts that accept the existence of market power will include the wealth transfer (cost component 2) in oil dependence cost estimates. Even among those analysts that agree on the existence of market power in the world oil market, debate remains concerning whether the exercise of demand side market power by the U.S. is an appropriate or effective response (i.e., the monopsony effect).

2. *What is the scope of the oil dependence cost estimate?* Scope can be thought of in two dimensions: 1) who the costs accrue to and 2) what types of oil are considered. The costs generated by market failures accrue to different market participants. Some oil dependence costs estimates focus on the efficiency losses of oil dependence on the global economy while others focus on the costs (both efficiency losses and pecuniary externalities) that accrue to particular market participants such as the United States. Thus, some oil dependence cost estimates reflect a global estimate of the costs of oil dependence while others are U.S.-specific estimates. Many oil dependence cost estimates arbitrarily focus only on oil imports. However, many relevant costs of oil dependence are not tied to only imported oil. For example, environmental

externalities associated with oil production and consumption arise from both foreign and domestic oil. Oil dependence costs estimates that focus only on foreign oil imports often ignore environmental externalities since these costs are thought to be beyond the scope of the analysis.

3. *What type of estimation approach is used?* Some oil dependence cost estimates capture the total oil dependence cost associated with a given level of oil imports. In contrast, other estimates capture the benefits to society of reducing U.S. imports by one barrel (oil premium). These two measures will differ simply because total costs are measured in dollars and the oil premium is measured in dollars per barrel. However, differences in these two measures may persist even after converting total and incremental cost estimates to similar units (i.e., dividing total costs by the number of barrels imported).

4. *What type of benchmark is used for the analysis?* Estimates of oil dependence cost are predicated on one of two benchmarks: 1) a first-best, perfectly competitive market; 2) the current state of the world given market failures and existing policy. Which benchmark is appropriate depends on whether an accurate estimate of the oil dependence costs is needed or an accurate estimate of the policy intended to address oil dependence.

5. *How well the estimate captures dynamic oil market process?* Virtually all oil dependence cost estimates account for the differences in short- and long-run elasticities. This difference in short-run and long-run elasticities is a fundamental component of estimates of the potential GDP losses, wealth transfer, monopsony effect and disruption costs. However, the difference between short-run and long-run adjustments causes market power to vary dynamically and causes producer and consumer surplus to vary dynamically as well. Some oil dependence cost measures

capture these dynamic adjustments only at equilibrium while others more fully account for the dynamic adjustment processes.

6. *Different sources of data, calibration of models, and treatment of uncertainty*. The most influential component of any oil dependence cost study is the supply and demand elasticities. Elasticity estimates are typically taken from existing studies. These studies have reached some consensus on the appropriate values for the short- and long-run price elasticity of oil demand. There is far less consensus in the literature on the responsiveness of world oil supply. Some variation in elasticity estimates can also arise depending on the period of the analysis and the country under study. Data-specific sources of variation in oil dependence cost estimates are also likely to arise due to the analysts accounting of oil supply disruption risks and the handing of various sources of parametric and model uncertainty.

Using welfare economic theory as our guiding framework, we find that there is nothing conceptually or theoretically incorrect with any of the existing oil dependence cost measures. Instead, we conclude that different oil dependence cost measures are designed to address different policy contexts.

To match the appropriate oil dependence cost measure to the appropriate policy context, this report introduces a two-stage taxonomy of oil dependence cost estimates. The first stage accounts for the market failures considered and the scope of the oil dependence cost estimate by identifying cost components (from eight different types of cost components) that arise in questions surrounding oil dependence. The second stage accounts for the appropriate method to use to estimate oil dependence costs by addressing the way the estimate will be used to inform domestic energy policy. According to this two-stage taxonomy, each oil dependence cost estimate is assigned a letter to identify the method used (second stage) followed by a series of numbers to identify which costs were included in the estimate (first stage). We then use this taxonomy to identify the ideal oil dependence cost estimate to use in twenty-two general policy contexts that often invoke oil dependence as an argument. The specific policy contexts are crafted to address common policy questions surrounding:

1. A carbon tax
2. Vehicle fuel efficiency standards
3. A tax on oil consumption
4. An oil import tariff
5. Tax credits for flex-fuel vehicles
6. Domestic oil production subsidy
7. Federal funding for energy R&D
8. Military presence in oil-producing countries
9. Management of the strategic petroleum reserve

It may also be desirable to start with a particular oil dependence cost measure and identify the policy contexts in which it should be applied. We use the taxonomy to compare and contrast two oil dependence cost measures: the Oil Security Metrics Model (OSMM) developed by Greene and Leiby (2006) and the oil import premium developed by Leiby, Jones et al. (1997) and updated in Leiby (2007).

The report also highlights five potentially fruitful new areas for future research related to oil dependence costs. These new areas for research would improve our ability to assess the validity of oil dependence cost estimates, address issues of parameter and model uncertainty, and gain a better understanding of the limits of current modeling approaches.

1. PURPOSE OF THE REPORT

U.S. oil dependence has been an important topic at the nexus of energy policy, economic, policy and national security since the early 1970s (Deutch and Schlesinger 2006). Oil dependence typically refers to the percentage of domestic oil consumption that is imported.[1] As shown in Figure 1, the percentage of U.S. petroleum consumption supplied by foreign sources has declined from a historic high of 60 percent to a recent historic low of 25 percent in a decade. Most of the impetus for concerns about oil dependence center on OPEC and its ability to influence world oil markets to the detriment of U.S. interests. However, the percentage of U.S. petroleum consumption supplied by OPEC has fallen to 16 percent while the percentage supplied by non-OPEC countries such as Canada has increased. Crude oil prices have also been stable or falling during this time reflecting a decline in OPEC market share (see Figure 2). These trends suggest that OPEC's ability to influence world oil prices is waning and, more generally, the costs of oil dependence are currently very low. However, the cost of oil dependence differs from the actual expenditures on crude oil imports due to market failures that plague world oil markets. Market failures suggest world oil markets are inefficient and this inefficiency signals that gains to the U.S. economy could be achieved by intervening in world oil markets to reduce overall U.S. energy intensity, discourage oil imports, or encourage domestic energy production. Large estimates of the U.S. oil dependence costs provide a strong economic justification for a variety of energy policies but smaller estimates suggest an economic justification for these policies may be lacking.

[1] Alternative measures of oil dependence include the amount of domestic oil consumption and estimates of the price elasticity of U.S. fuel supply and oil demand.

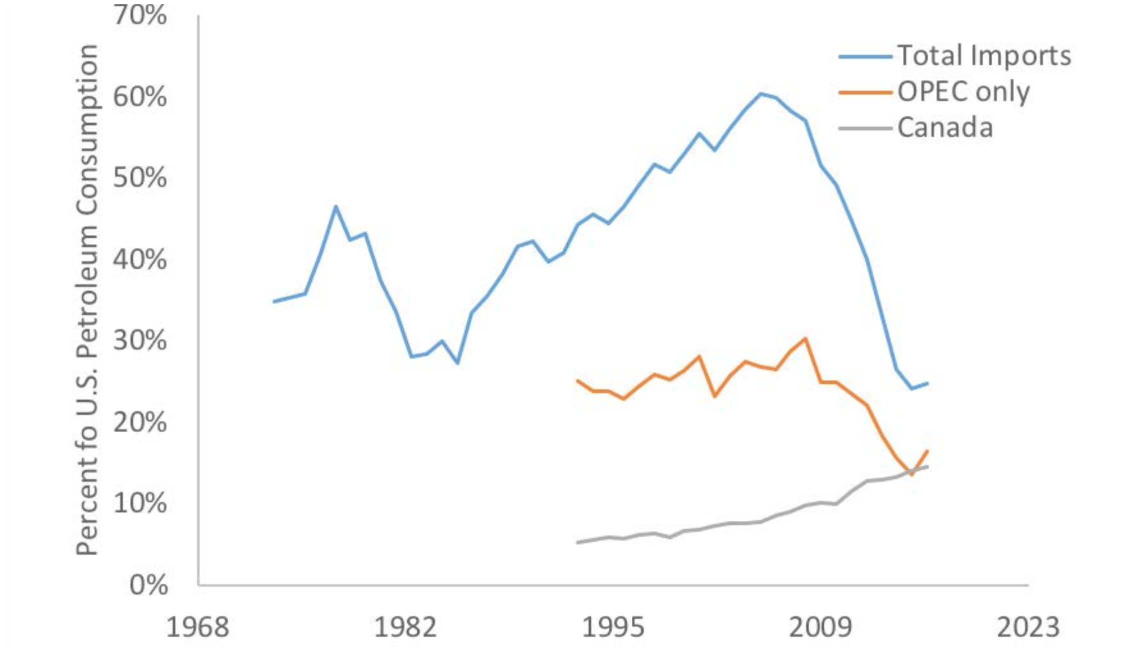

Figure 1. U.S. Net Imports of Crude Oil as a Percentage of Total U.S. Oil Consumption

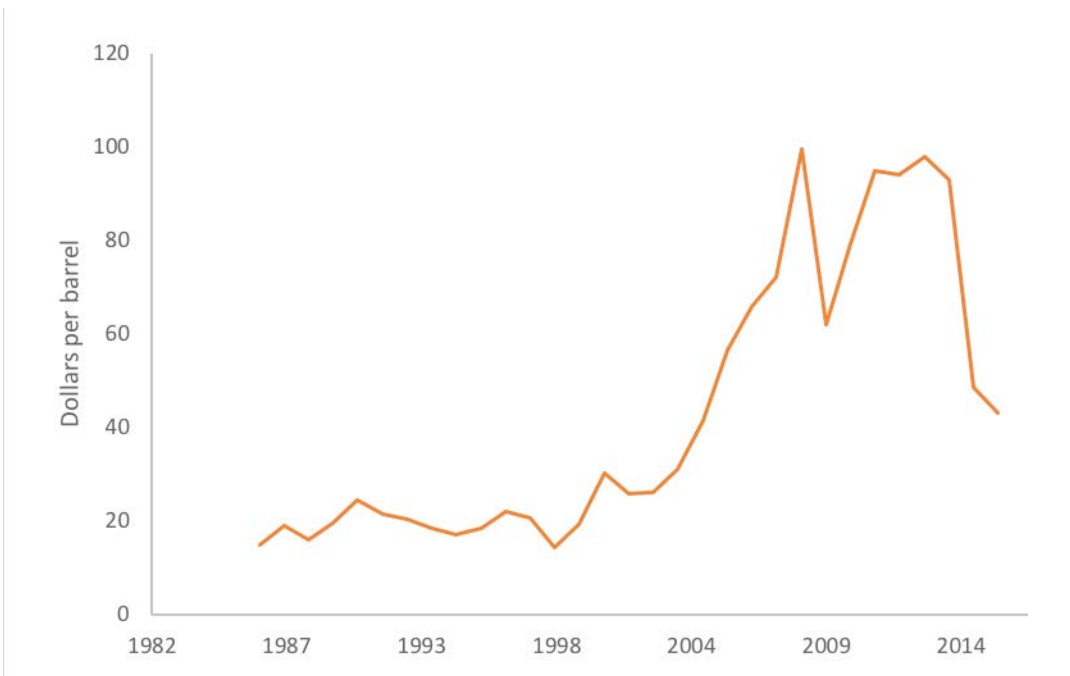

Figure 2. Cushing, OK WTI Spot Price FOB, 1983-2016

The idea that the true cost of oil dependence is not reflected in the price of oil is widely held. However, there is far less agreement on the drivers of this discrepancy. Because they signal the *potential* gains of a variety of energy policies, a large and contentious literature has focused on estimating the costs associated with oil dependence (Parry and Darmstadter 2003).

Estimates of the cost of U.S. oil dependence have been a hotly debated topic with estimates ranging from $0 to over $14 per barrel. Based on such a wide variation in oil dependence cost estimates, many conclude that either 1) the cost of oil dependence has been changing over time and/or 2) there is considerable uncertainty in oil dependence cost estimates. Neither conclusion is entirely inaccurate. The costs of oil dependence will change based on market forces, new technologies, and civil unrest in oil producing countries. There are also important sources of uncertainty (uncertainty in model parameters, inability to predict oil supply disruptions) associated with estimating oil dependence costs such that any estimate should be viewed as a "best guess" or expected estimate.

However, attributing all of the variation in oil dependence cost estimates to changing conditions and uncertainty would be misleading. The wide variation in estimates is not surprising given the different methodologies (e.g., econometric analysis, simulation models) and data sources used to develop these estimates. All estimates of oil dependence costs are based on models. By definition, a model is more abstract than the system it represents. Abstraction allows analysts to eliminate unnecessary detail and focus on the specific elements of the system that are pertinent to the motivations of the study (provide costs associated with a particular oil market failure; provide benefits of a policy that will reduce oil imports). However, abstraction introduces inaccuracy. Thus, each analysis introduces a unique form of inaccuracy determined by how the analyst views the trade off between abstraction and inaccuracy. Even if these differences could be resolved, there are two other often-overlooked reasons oil dependence cost measures should be expected to vary.

The first is the lack of agreement on a definition of oil dependence. Oil dependence has been defined as the amount of domestic oil consumption and the percentage of domestic oil consumption that is imported. These simple definitions of oil dependence are misleading since they suggest that minimizing oil dependence can be achieved by minimizing oil consumption or oil imports. From an economic perspective, oil consumption and oil imports are not the problem. The problem is the variety of potential market failures that manifest as inefficiently high domestic oil consumption and/or oil imports. Taking a market failure perspective provides a more accurate depiction of the oil dependence problem. But it also suggests that the oil dependence problem is actually the combined result of multiple factors including: 1) the short-run inelasticity of oil supply and demand, 2) the imperfect use of monopoly power in world oil markets by a few nations that hold a disproportionate share of the world's oil reserves, 3) reliance on imports, and 4) the importance of oil to the U.S. economy (Greene, Jones et al. 1998). Thus, the oil dependence problem is more complicated than any single measure of oil consumption or oil imports. Due to the lack of a consensus definition of oil dependence, the literature calculates oil dependence costs that include some or all of the following:

- imperfect competition
- vulnerability to supply shocks
- environmental externalities
- national security spending to maintain oil supplies
- decreased incentives for new technology adoption (technology "lock-in") that arise from oil's dominant role as an energy source

Even if consensus could be reached on a precise definition of oil dependence, ambiguity over the scope of oil dependence *costs* would persist. Costs could be interpreted as the losses generated by market inefficiencies or changes in the distribution of income between U.S. consumers and producers and foreign oil producers. Typically, economists focus only on the former category of costs when designing policy. However, the latter cost category (a redistribution of income) may still be a concern for U.S. policymakers since they involve wealth transfers out of the U.S. This lack of consensus has led to some unnecessary confusion and conflicting policy prescriptions aimed at addressing U.S. oil dependency.

The second is the purpose of the estimate will influence the approach taken to estimate oil dependence. Oil dependence costs have been used to help develop or justify existing policies related to climate change, vehicle fuel efficiency, trade, and energy research and development. Some of these policies are meant to reduce overall energy intensity, some are meant to discourage oil imports, and others are meant to encourage domestic energy production. Even within a single policy context, oil dependence cost estimates may be used to motivate the policy or research and development (R&D) action, design a policy to address oil dependence, or evaluate existing policies and R&D programs. If analysts anticipate their estimate will be used for the former (motivate), they strive for a "clean" measure that filters out the effect of other market failures and existing policies to arrive at a more complete measure that accurately depicts the costs of oil dependence (however that is defined). If analysts anticipate their estimate will be used for the later (evaluation), they strive for a "realistic" measure that more accurately reflects the possible, realized benefits of policies intended to reduce oil dependency. If analysts anticipate their estimate will be used to design policy, the type of policy (e.g., import tariff, domestic production tax credit, federal research and development funding) will influence how analysts define oil dependence and the scope of oil dependence costs.

Clearly, oil dependency costs arise from different economic phenomena so one should not expect a single measure that is applicable in all settings (Dorfman 1981, Bohi and Montgomery 1982). Similar issues arise when economists estimate the value of a statistical life (Viscusi and Aldy 2003). Thus, the appropriate question is not which measure of oil dependence is correct but which measure is correct in a particular policy context. This report reviews some of the reasons oil dependence cost estimates differ through the lens of welfare economic theory, which we argue is the appropriate framework for investigating oil dependence costs. Organizing our literature review based on a welfare-economic taxonomy provides more clarity on the discrepancies (some of which are large) in seemingly similar measures of oil dependence costs. This review is used as a foundation for a new typology of oil dependence costs that focuses on the policy context and welfare economic foundations. This typology is then used to illustrate how the policy context influences the appropriate measure of oil dependence costs. The primary focus of the report is on determining the appropriateness of particular measures in particular policy settings and does not attempt to assess the magnitude or accuracy of any particular estimate.

2. WHAT DIFFERENTIATES OIL DEPENDENCE COST MEASURES?

The range of oil dependence cost estimates found in the literature can confound attempts to develop new energy policy and quantify the benefits of existing policies intended to reduce reliance on foreign sources of oil. Even when controlling for the variety of modeling approaches and data sources used to estimate these costs, imprecise definitions of oil dependence and different end uses for these estimates suggest a consensus measure is unlikely to emerge.

In this section, we discuss six dimensions that help explain the wide variation in oil dependence cost measures found in the literature.

2. 1. MARKET FAILURES: EXTERNALITIES AND IMPERFECT COMPETITION

The impetus for measuring oil dependence costs is the belief that the world oil market violates the first fundamental theorem of welfare economics. The first theorem states that the resource allocation that results from a market cannot be improved without making at least one individual worse off provided 1) markets are complete and 2) market participants are price takers. If both of these provisos hold, the world oil price would represent the true cost of importing foreign oil and there would be no reason to estimate oil dependence costs. However, if either of these provisos are violated, there is an inefficiency in the world oil market in that the market could be adjusted to make some individuals better off without making anyone worse off. In other words, markets are not maximizing the net benefit of the world's oil reserves. This inefficiency becomes an economic rationale for government intervention in markets. In the presence of a market failure, well-crafted energy policies could improve outcomes generated by private markets.

The two provisos in the first fundamental welfare theorem serve as a valuable foundation for categorizing and defining oil dependence cost estimates. There is wide agreement that world oil markets are incomplete because the world oil price fails to capture a variety of external costs. External cost are the costs of oil imports that are not included in the market price of oil:

- **Environmental externalities**: Oil markets are not complete since the production and consumption of oil generates pollution. This pollution generates real economic costs that are not included in the world price of oil. Faced with an inefficiently low oil price, U.S. citizens consume too much oil (both from foreign and domestic sources) and social welfare would be improved by reducing oil consumption. The environmental externalities associated with the CO_2 produced from burning oil are captured by well-known social costs of carbon measures and regularly updated.

Estimates of the environmental externalities associated with other pollutants such as NOx and carbon monoxide are also frequently used by federal agencies (e.g., EPA) for the purpose of federal rulemaking. However, this source of market failure is often omitted from oil dependence cost estimates since it is rooted in both foreign and domestic source of oil.

- **Military expenditures**: Oil markets are also incomplete because the U.S. government makes large military expenditures in order to ensure the stability and consistency of oil supplies. Like an environmental externality, these military expenditures are not included in the world price of oil. Unlike an environmental externality, this type of market failure only results in U.S. citizens consuming too much oil from foreign sources. Consumption from domestic sources may or may not be affected by this market failure. This source of market failure is often omitted from oil dependence cost estimates due to the difficulty in attributing specific military expenditures to securing and stabilizing oil supplies.

- **Energy efficiency paradox**: There is also considerable evidence that oil markets may be incomplete because consumers undervalue energy efficiency. The "energy efficiency gap" or "energy paradox" arises when consumers forgo energy efficient investments that yield a positive net present value (Jaffe and Stavins 1994). The gap or paradox reflects the idea that consumers should adopt energy efficient products if they yield a rate of return that is higher than could be earned elsewhere in the economy. However, the implicit discount rate (the rate of return needed to drive the net present value of the investment to zero) for observed energy efficiency investments can be much higher than any reasonable risk-adjusted discount rate. For example, Dreyfus and Viscusi (1995) suggest the implicit discount rate for a more fuel-efficient automobile is 11-17 percent. Mau, Eyzaguirre et al. (2008) find the implicit discount rate for a hybrid electric automobile is 21-49 percent. Some research suggests the energy efficiency paradox is merely a result of model and measurement error and does not really exist. However, proponents of the energy efficiency paradox argue that is arises due to consumer behavior and market failure

(Gillingham and Palmer 2014, Gerarden, Newell et al. 2015). Proponents of consumer behavior and market failure argue the energy efficiency gap exists due to inefficient distortion in markets or irrational characteristics of human behavior. If energy efficiency is undervalued, demand for petroleum products will be too high and energy efficiency R&D will be too low. In both cases, the energy efficiency paradox works to increase the cost of oil dependence.

There is also wide agreement that oil market participants are not price takers. A cartel of producers known as OPEC consciously constrict oil supply and raise the world price of oil to increase oil revenues for OPEC members. OPEC's ability to influence world oil prices is determined by OPEC's market share which is influenced by:

- **Price elasticity of demand in the short and long run**: Studies place the price elasticity of demand for oil around 0.2 to 0.3 with slightly higher estimates in the U.S. at 0.4 to 0.5 (Hamilton 2008). For a summary of various demand elasticities in the transportation sector see Litman (2017).
- **Income elasticity of demand**: Income elasticity is near unity in developing countries but substantially less than one for the U.S.
- **Supply responsiveness of producers who are not in OPEC (competitive fringe):** OPEC members have over 80% of the world's proven oil reserves but there is a competitive fringe who do not actively coordinate to exert market power (see Table 1).
- **Compatibility of interest among cartel members:** While OPEC members are at the top of the list of proven oil reserves, there is a great deal of variation in reserves among member countries. Venezuela at 25 percent of OPEC proven reserves has a greater incentive to preserve OPEC market power than Angola who holds less than 1 percent of OPEC proven oil reserves.

Table 1. 2016 proven oil reserves among OPEC members and competitive fringe

	Billions of barrels	Share of OPEC proven crude oil reserves
Venezuela*	300	25%
Saudi Arabia*	269	22%
Canada	171	
Iran*	158	13%
Iraq*	143	12%
Kuwait*	104	8%
United Arab Emirates*	98	8%
Russia	80	
Libya*	48	4%
Nigeria*	37	3%
United States	37	
Kazakhstan	30	
China	25	
Qatar*	25	2%
Brazil	16	
Algeria*	12	1%
Mexico	10	
Ecuador*	9	<1%
Angola*	8	<1%
Azerbaijan	7	

* OPEC members
Source: The World Factbook 2016. Washington, DC: Central Intelligence Agency.

The inefficiently high price of oil has real costs to U.S. consumers. However, the size of this particular cost is determined by the combination of factors listed above.

Analysts have also pointed out that **supply shocks** may lead to losses in efficiency that would warrant inclusion in oil dependence cost estimates. Oil supply shocks account for about 40 percent of oil price fluctuations (Caldara, Cavallo et al. 2017). Supply shocks alone would not constitute a market failure. Nevertheless, market failures elsewhere in the economy may prevent slow capital and labor adjustments in response to the shock. A supply shock could also constitute a market failure if it was the result of deliberate exercise of market power by OPEC suppliers. Thus, the argument for considering supply shocks in oil dependence cost estimates relies on both incomplete and imperfectly competitive markets.

Like most markets, world oil markets almost certainly suffer from market failures. Because of market failures, we can conclude that the world oil price will not equal the efficient price of oil that would maximize the net benefit of the world's oil reserves. We can also conclude that the world oil price will not reflect the actual marginal cost of oil imports. This wedge between the world oil price and the marginal cost of oil imports is the motivation for estimating oil dependence costs. However, one of the fundamental explanations for differences in oil dependence cost estimates is disagreement over which market failures should be considered.

This brings us to a critical point: **All oil dependence costs are motivated by market failures but not all market failures are due to external costs of oil.** Market failures imply the price of imported oil is not equal to its marginal cost: $P \neq MC$. Inefficiencies arise as oil consumers are responding to a price signal that does not accurately reflect the true cost of producing and importing oil. The negative environmental externality and the public good problem associated with military expenditures imply $P < MC$. Here, prices are a poor signal of the true costs of oil imports because some of these costs are external to the world oil market. The oil dependence costs estimates are attempting to capture external costs that are not valued in an existing market. The market failure associated with a noncompetitive world oil market implies $P < MC$. Here, oil dependence cost estimates are attempting to capture the lost GDP that results from inefficiently high oil prices. This lost GDP is not external to the market. Thus, oil dependence costs defined as the cost of oil imports not included in the world price would only be accurate if the oil dependence costs ignored the costs originating from imperfect competition in the supply of oil. many analysts exclude costs form oil dependence costs estimates simply because these costs are not externalities (Brown and Huntington 2010, Council 2010, Bohi and Toman 2012). Excluding components of oil dependence costs measures simply because they are not externalities overlooks the costs generated by imperfect competition in oil supply.

Oil dependence costs would be more accurately defined as the costs that arise when prices are an imperfect signal of the true cost of oil consumption. All costs that arise from 1) incomplete world oil markets (i.e., external costs) and 2) imperfectly competitive world oil markets should be included in oil dependence cost estimates.

2. 2. SCOPE: IMPORTS AND PECUNIARY EXTERNALITIES

Analysts must also address more fundamental questions about scoping their analysis. Many theoretical impacts of oil dependence are often excluded because they are difficult to measure and arbitrarily viewed as beyond the scope of the analysis (e.g., military and political costs). Scoping may also address questions about whether the oil dependence cost estimate should account for global costs or simply costs that accrue to the U.S. economy. In other instances, the scope of the analysis is defined as oil imports leading potentially large oil dependence costs to be excluded because they apply to all oil consumption and not simply oil imports (e.g., environmental externalities). As a result, oil dependence costs estimates may differ simply because they account for different economic phenomenon. The following is a list of the largest and most common cost components that have been included in oil dependence cost estimates:

- **Potential GDP losses:** Domestic producer and consumer surplus losses. Losses depend on the size of the price change and the slopes of the U.S. supply and demand curves.
- **Wealth transfer:** The wealth transfer from U.S. consumers to foreign producers due to monopolistic pricing of oil.
- **Monopsony effect:** the effect of U.S. import demand on the long-run world oil price
- **Disruption costs:** costs incurred during supply disruptions. This cost component typically has two parts: 1) increased wealth transfer from domestic consumers to foreign producers during supply disruptions and 2) temporary GDP losses that result from macroeconomic contraction and dislocation during supply disruptions.
- **Military security costs:** the cost of maintaining a military presence to ensure stable and consistent oil supply from unstable regions
- **Strategic petroleum reserve costs:** the costs of maintaining the SPR

- **Environmental externalities:** External costs due to the production or consumption of foreign oil.

- **Political consequences of oil wealth:** These costs focus on how foreign producers may use oil wealth to act independently and against U.S interests.

Virtually all oil dependence costs estimates account for potential GDP losses. The majority of oil dependence costs estimates account for the wealth transfer, monopsony effect, and disruption costs though see Brown and Huntington (2010) for an important exception. Many studies account for the strategic petroleum reserve but there is often little consistency in how this cost component is calculated. Far fewer existing oil dependence costs estimates account for military security costs, environmental externalities, and political consequences of oil wealth). The cost of negative environmental externalities associated with producing and consuming oil are commonly estimated. Prominent examples include the social cost of carbon estimates, which place the negative costs of CO_2 generated through burning oil at $43/ton. The cost of the CO_2 generated through burning foreign oil could easily be estimated by accounting for quality differences between foreign and domestically produced oil. However, these external environmental costs are typically excluded from oil dependence cost estimates since these costs arise from the burning of both foreign and domestic oil. Military security costs, political consequences of oil wealth, and the cost of maintaining the SPR are rarely included due to the difficulty in estimating these costs. While the complications associated with estimating these costs are substantial, it is important to remember that omitting these costs effectively assumes that these costs are zero. Any estimate of the cost of oil dependence that ignores these cost components should be viewed as a lower bound estimate.

The magnitude of each of the cost components will also vary depending on whether the analysis take a global or U.S. perspective. As discussed in the previous section, oil dependence costs would be more accurately defined as the costs that arise when prices are an imperfect signal of the true cost of oil consumption. This definition is more precise but still leaves room for misinterpretation and confusion since costs generated by market failures accrue to different market participants. In other words, this definition is implicitly framed by world oil markets. Oil dependence cost estimates are rarely created to identify the costs of oil dependence on the global economy. The vast majority of oil dependence cost estimates are created and used to inform different market participants (i.e., countries). This brings us to another important point: **All oil dependence cost estimates are motivated by inefficiencies but most estimates capture more than just the inefficiencies.** Each type of market failure creates two types of costs:

1. The inefficiencies generated when a market failure occurs. If the value of the world's oil resources are viewed as a pie, inefficiencies would imply shrinking the pie. Since value captures elements of both supply and demand for oil, shrinking the pie harms both producers and consumers of oil. These inefficiencies are often referred to as a deadweight loss since all market participants are harmed. The harm that accrues to the U.S. economy is the loss of GDP due to higher monopoly price of oil.

2. Income or wealth transfers between market participants. Wealth transfers affect the distribution of the world's oil wealth but do not alter the efficiency of the markets. In other words, wealth transfers alter the size of the pie piece each market participant receives but does not alter the size of the pie. These wealth transfers may be an unintended byproduct of an incomplete world oil market. In the case of imperfect competition, these wealth transfers are the driver of the market failure and the inefficiencies are a byproduct of the wealth transfer. Wealth transfers are often viewed as pecuniary externalities since these transfers do not compromise the efficiency of world oil markets and may actually be necessary forces to ensure efficient world oil markets. However, when wealth is transferred out of the country, the size of the wealth transfers may be a concern for policymakers even though the market is efficient.

Figure 3 illustrates the difference between a deadweight loss and wealth transfer for imperfect competition in world oil supply. For simplicity, we focus on the U.S. and OPEC and ignore the rest of the world. A perfectly competitive world oil market would find the world oil price equal to the competitive market price. A perfectly functioning cartel would find it optimal to price their oil where marginal revenue equals their marginal cost. In the absence of production from other countries, this would determine the world oil price. The world oil price with cartel pricing will always be higher than the competitive market price.

Foreign and domestic producers gain from cartel pricing while U.S. consumers are negatively affected by cartel pricing. The cartel loses producer surplus equal to area D but gains a wealth transfer from U.S. oil consumers equal to area B. U.S. oil consumers lose surplus equal to area C. U.S. domestic production will expand until the U.S. long-run supply equals the higher world oil price. This results in a surplus gain for U.S. oil producers equal to area A. This gain to U.S. oil producers is offset by losses to U.S. consumers who now must pay a higher price for domestically produced oil (area E). Thus, the expansion of domestic production mitigates the wealth transfer from the U.S. to foreign producers but it is merely a wealth transfer within the U.S. economy. The deadweight loss in this simple example is equal to area C and D. The wealth transfer from U.S oil consumers to OPEC is equal to area B. The wealth transfer from U.S. oil consumers to U.S. oil producers is equal to area A+E.

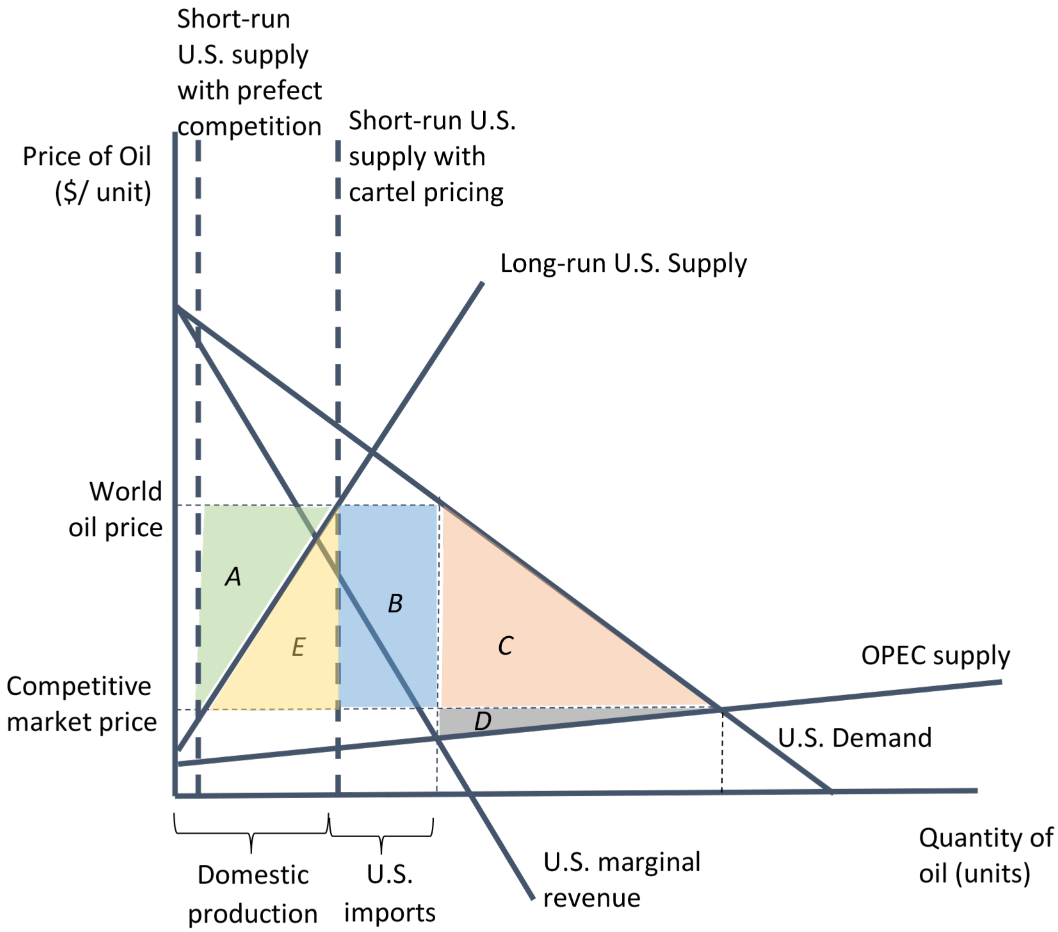

Figure 3. Deadweight loss and wealth transfers due to cartel pricing

Oil dependence cost estimates can be either viewed as inefficiency estimates or cost estimates depending on how they treat the deadweight loss and wealth transfers. A strict welfare economic interpretation of oil dependence costs would focus on the deadweight loss since it is an objective measure of loss from the market failure – a loss in market efficiency. Nearly all estimates of oil dependence costs account for the deadweight loss. Clearly, the impacts to the U.S. economy extend beyond the deadweight loss. However, moving beyond this efficiency definition of oil dependence costs requires a subjective assessment of which wealth transfers should be included. If oil dependence costs are costs that accrue to the U.S. as a whole, only area B should be included. If oil dependence costs are costs that accrue to U.S. consumers, there is an argument for including both A and B. There is also an argument for excluding area D since it is the efficiency loss experienced by foreign producers. The ambiguity about which wealth transfers should be included is due to differences in the scope of oil dependence cost estimates: U.S. versus the world.

The distinction between deadweight losses and wealth transfers is at the heart of an ongoing debate in the literature surrounding imperfect competition on the demand side. The U.S. has traditionally been the largest consumer of oil. Unlike other countries whose oil consumption constitutes a small proportion of total consumption, increases in U.S. demand can increase the world price of oil. Because U.S consumers do not coordinate to constrict their demand, each individual consumer fails to account for the price increase that accompanies an increase in their demand. Assuming coordination can be achieved costlessly, this lack of coordination is represented by the outward shift in U.S. demand in Figure 4. The lack of coordination among U.S. oil consumers inflicts economic harm on the U.S. economy, as the increased price constitutes a transfer of wealth from the U.S. to producing countries. This wealth transfer is shown as area F in Figure 4. But since the monopsony effect is an example of imperfect competition and not an externality, the lack of coordination also eliminates a deadweight loss and increases market efficiency. Part of this efficiency gain (area H) accrues to U.S. consumers. Thus, the component of oil dependence costs attributable to the monopsony effect should be the forgone wealth transfer minus the increase in efficiency gain that accrues to the U.S. economy: area F-H. If there are monitoring and enforecement costs associated with coordinating the reduction in U.S. demand, these transaction costs would also need to be subtracted from F.

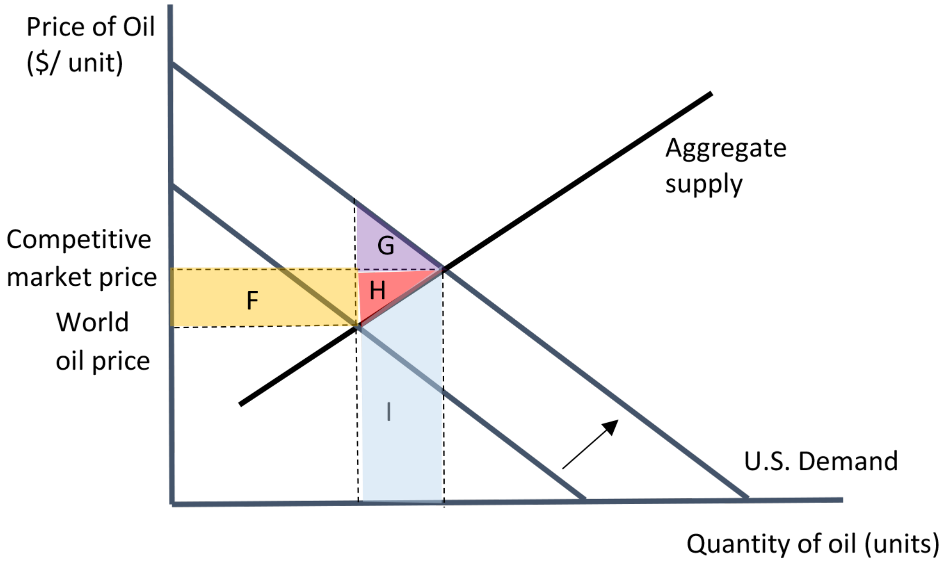

Figure 4. Wealth transfers and deadweight losses that arise if the U.S. exerts market power

Many analysists argue that the monopsony effect should not be included in oil dependence costs estimates because the exercise of market power by the U.S. creates a market failure where one did not previously exist (Brown and Huntington 2010, Council 2010). This argument is problematic. It is true that exercising market power on the demand side would introduce a market failure and generate an additional deadweight loss (shown as areas G and H in Figure 4). However, the wealth transfer from foreign producers to U.S. consumers will almost certainly outweigh the deadweight loss that accrues to the US economy. If the monitoring and enforcement costs needed to ensure the reduction in U.S. demand were small, the failure to exercise market power would generate real *net* costs to the U.S. economy.

It is also unclear whether the U.S exercising market power would even result in a loss of market efficiency. The introduction of a market failure in the presence of an existing market failure (such as OPEC exerting market power) could be welfare improving according to the theory of second best (Lipsey and Lancaster 1956). The theory of second best states that the conditions that define the first best market outcome will not be the conditions that ensure the second best market outcome. Consider the following simple model. Assume we have one consumer, n goods (one of which is oil), one firm, and a fixed supply of one primary factor of production that is not desired by the consumer such as labor. The consumer gets utility from the goods, $U(q_1, ..., q_n)$, and each good is used as an input to the production of other goods $F\left(q_1,\cdots,q_n;\bar{L}\right)$. A first-best, Pareto optimal market outcome would yield the quantities of each good that maximize the consumer's utility subject to the current production technologies. This first- best or perfectly efficient market is defined by a set of conditions for each good:

$$U_i = \lambda F_i$$

where $U_i = \frac{\partial U}{\partial q_i}, F_i = \frac{\partial F}{\partial q_i}$ and $i = 1,2, ..., n$ indexes the goods produced in the economy. This condition says that when a market is efficient, it balances the marginal utility for a good with the goods marginal value product. In other words, a market is inefficient if it leads to goods produced at levels where the goods value in the production process is less than the value generated if the good were consumed directly. Because production and consumption of any good in the economy could be linked to production and consumption of other goods, it helps to think of this first-best, efficient market condition as:

$$\frac{U_i}{U_j} = \frac{F_i}{F_j}$$

where $j \neq i$. In other words, the consumer's willingness to substitute an additional unit of one good for another (marginal rate of substitution) should equal the rate of technical substitution in the production process.

Now assume a market failure exists in the world oil market such that $\frac{\partial U}{\partial q_{oil}} = k\frac{\partial F}{\partial q_{oil}}$ where $k \neq \lambda$ is a positive constant. This condition could arise due to market power on the supply side that increased the price of oil above its optimal shadow value. With this pre-existing market failure, the condition that describes the efficient level of production of other goods in the economy is

$$\frac{U_i}{U_j} = \frac{\lambda F_i + \mu\left(U_{oil,i} - kF_{oil,i}\right)}{\lambda F_j + \mu\left(U_{oil,j} - kF_{oil,j}\right)}$$

The condition above represents the second-best condition for the economy in the presents of a market failure in the oil market. In a second-best economy, the marginal rate of substitution will not necessarily equal the rate of technical substitution. How much the first-best and second-best economies differ from one another depends on the signs and magnitudes of the cross partials associated with the world oil market: $U_{oil,i}, F_{oil,i}, U_{oil,j}, F_{oil,j}$. Since the market power exerted by oil producers and the environmental externalities associated with oil consumption eliminate the possibility of the market reaching the first best outcome, there is no guarantee that abstaining from the introduction of a second market failure (demand side market power by the U.S.) will be welfare improving.

Some analysts include the monopsony effect in oil dependence costs estimates because of the presence of monopoly power exerted by OPEC (Hogan and Broadman 1988, Leiby 2007). The U.S. choosing to exert its market power means that the wealth transfer from foreign oil producers to U.S. consumers in area F is intended to counteract the wealth transfer in area B. However, the presence of an existing market failure complicates the analysis. First, the costs that arise from the U.S. failing to exert market power will certainly be smaller than F-H in the presence of an existing market failure. Figure 5 considers the case where the U.S. exerts demand-side market power in response to supply-side market power by OPEC. The red lines show U.S. demand and marginal revenue if the U.S were to coordinate and reduce demand. While the U.S. decision to exert market power does erode the wealth transfer to foreign producers (area B), part of this reduction in the wealth transfer is just an increase in the size of the deadweight loss (areas C and D). Only area K represents a transfer from foreign producers back to the U.S consumers. Once the producer surplus losses that accrue to domestic oil producers (area J) and any monitoring and enforcement costs needed to coordinate the demand reduction are accounted for, it is easy to see how exerting market power may not be advantageous to the U.S. The benefit of reducing U.S. imports will be much smaller than the difference in the import bill attributable to the decline in price.

There are also two other reasons to believe that the monopsony effect may be a mirage. First, the U.S. has not chosen to act on its market power because they believe the benefits of doing so would be transitory. If so, a constant monopsony premium would not be reflective of the true benefits of the U.S exerting monopsony power. A dynamic analysis would be needed to estimate the monopsony benefit that accounts for the decay in the benefits as affected parties retaliate. Thus including the monopsony effect as a constant premium attached to oil imports will overestimate the true benefits of the U.S. exerting its monopsony power but excluding it from the analysis will underestimate the benefits. Unfortunately, since the U.S. has not exerted its market power in the past, it is difficult to know when and how market participants would respond to a sudden, strategic change in U.S. demand. However, given the emergence of China as an oil consumer, the U.S.'s ability to exert demand-side market power may be waning. Second, while the theory of second best undermines traditional arguments against including the monopsony effect in oil dependence costs estimates, it also highlights the need to consider the magnitude of the monopsony effect in a general equilibrium setting where prices of other goods in the economy (cars, electricity, etc.) adjust in response to the U.S. contraction of oil demand. To date, most (if not all) estimates of oil dependence costs hold the prices of other goods in the economy constant.

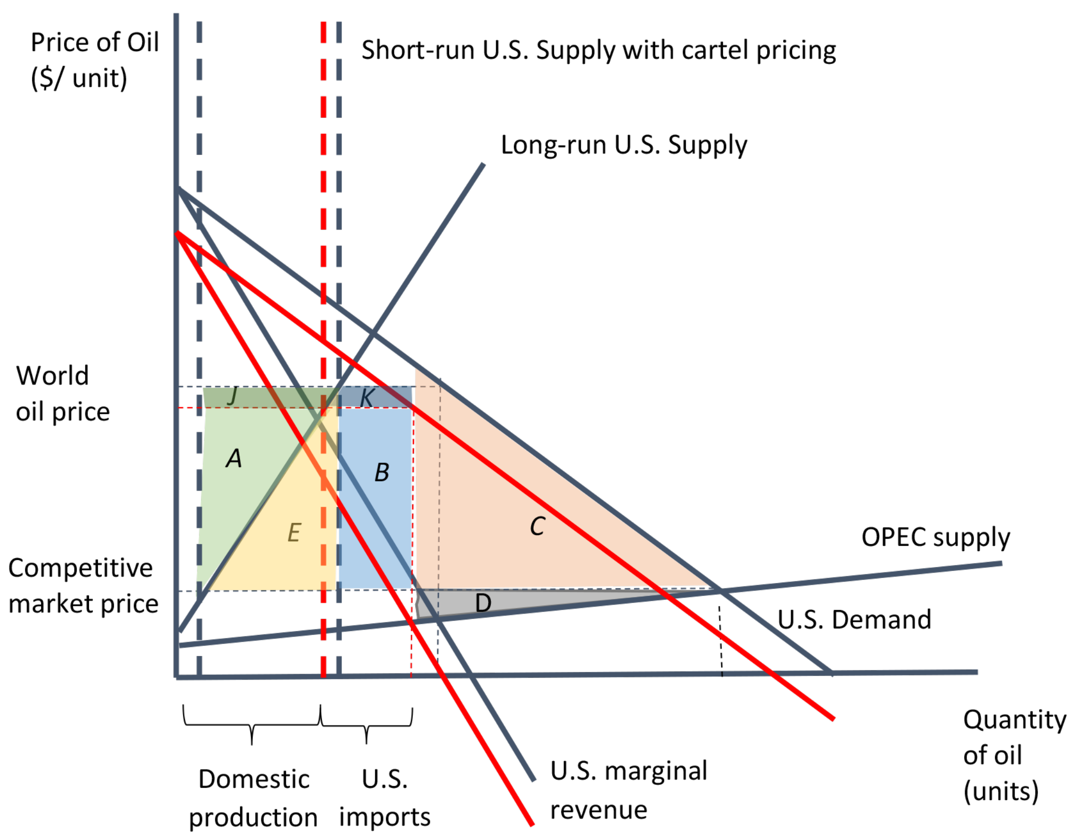

Figure 5. Monopsony effect when OPEC exerts market power on the supply side

2. 3. *APPROACH: TOTAL COSTS VERSUS PREMIUMS*

There are two main ways that researchers have approached the cost of oil dependence in the literature: total costs and oil import premiums. To illustrate, we will return to the diagrammatic depiction of one of the primary motivations for oil dependence costs: supply-side market power (Figure 6). The first approach calculates the total oil dependence cost associated with a given level of oil imports. This approach calculates the difference in the total costs associated with oil imports in the current state of the world and a hypothetical, counterfactual economy. Most often, this hypothetical economy is defined as the first-best (Pareto optimal) world oil market that would satisfy the first fundamental welfare theorem. This approach would be similar to estimating the relevant areas in figure 6. For example, if one were to ignore the monopsony effect, oil dependence costs to the U.S. economy as a whole based on a perfectly competitive world oil market would be B+C. These costs, which accrue entirely to U.S. oil consumers, include both the consumer surplus losses (C) and the wealth transfer to foreign produces (B). Oil dependence costs from the perspective of U.S. consumers would be B+C+E.

The second approach is to calculate an oil premium. This approach estimates the benefits to society (in dollars per unit) of reducing U.S. imports by one unit (i.e., barrel). Parry and Darmstadter (2003) define the oil premium (marginal external costs of oil consumption) as the difference between the private and social costs of petroleum consumption measured in dollars per barrel. This difference between private and social costs could be the same as the difference between the current state of the world and first-best economy considered in the total cost measure. Identifying the oil import premium would be similar to identifying the change in price needed to achieve a desired market outcome. For example, if one were to ignore the monopsony effect, the oil premium for the case in Figure 6 would be the difference between the world price and the competitive market price. There is a relationship between the total cost estimates of oil dependence costs and the oil premium: $total\ cost = premium \times \left(I + \frac{1}{2} II\right)$. As a result, apparent differences between total cost estimates of oil dependence costs and premium estimates has more to do with the types of oil dependence costs included in the analysis and less to do with whether they are measured in total or marginal terms. While both approaches can account for the fact that market efficiency is defined by the costs and benefits of the marginal barrel of oil they do this in different ways.

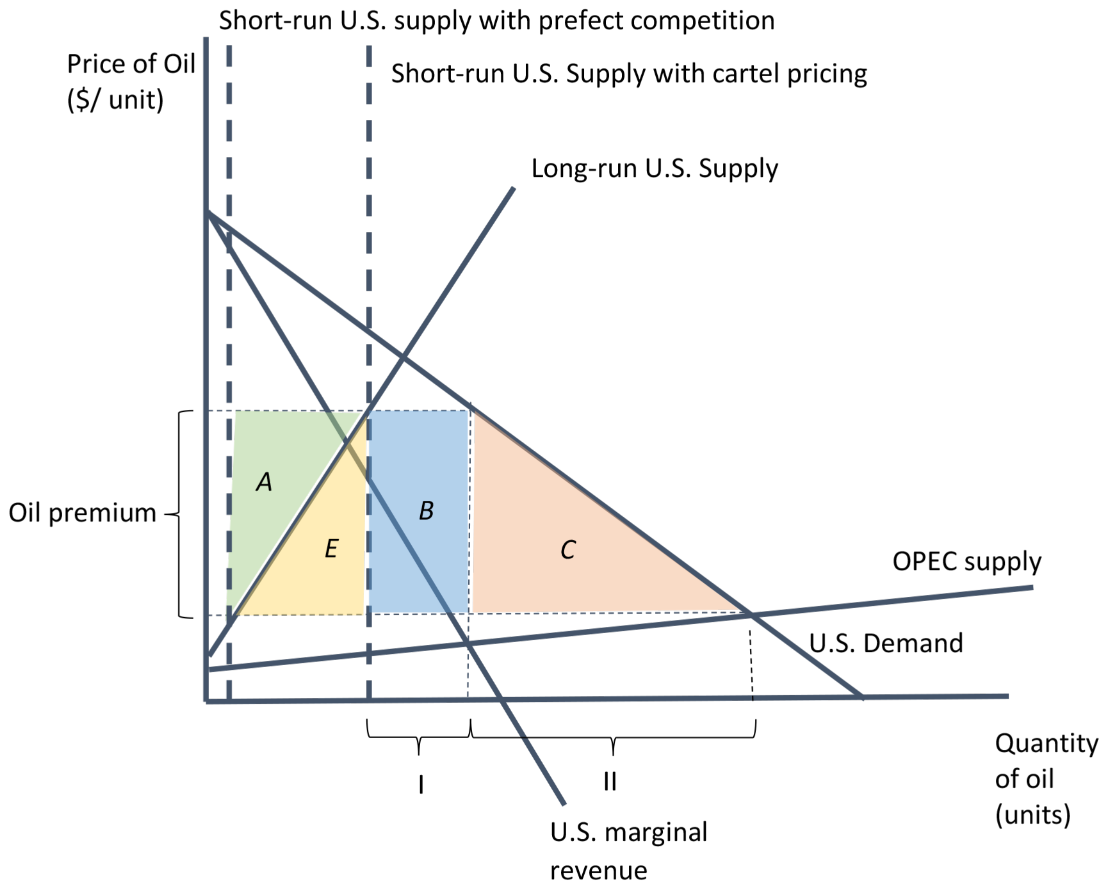

Figure 6. Difference between total cost and premium estimates of oil dependence costs

While the total cost estimates can theoretically be recovered from premium estimates, there are other policy-related considerations to take into account when choosing an approach. When externalities are the dominant oil dependence cost, premium estimates give policy makers a useful guidepost for developing market-based approaches to addressing the oil dependence problem. In this case, the world price of oil is below the price that would emerge in a complete market inclusive of all externalities. Oil dependence costs can be internalized simply by setting a tariff equal to the oil premium. As a result, premium estimates are often interpreted as an optimal import tariff (Hogan and Broadman 1988). This is incorrect since not all oil dependence costs are externalities. For example, when oil dependence costs are characterized by supply-side market power, the world price of oil is above the competitive market price. Here a market-based approach is misleading. The premium would suggest that U.S. consumers receive a subsidy equal to the premium for each barrel of oil consumed. This would lower the effective price U.S. consumers pay to the perfectly competitive market price; but the federal government would simply be reimbursing U.S. citizens for the lost surplus and income that results from cartel pricing. This strategy would not be sustainable since the transfer of wealth from U.S. consumers to OPEC would still be occurring. Market power on the demand side (monopsony effect) is more conducive to a market-based approach informed by a premium estimate. Previous work has routinely treated the monopsony effect as an external cost in order to include it in premium estimates. While the monopsony effect is not an external cost, setting a tax on oil consumption equal to the marginal monopsony effect could work to develop coordinated market power by the U.S. However, this premium would be intended to coordinate market power and not internalize external costs. Unlike marginal external costs, there is not a strong theoretical case for including the marginal monopsony effect in oil import premium estimates. In addition, the previous section highlights numerous reasons the monopsony effect may be smaller than reported in the existing literature. Thus, a premium estimate has a limited ability to inform a market-based approach to the oil dependence problem.

Total costs estimates can be more useful for certain types of policy responses to the oil dependence problem. Many of the market failures common in the oil dependence literature do not lend themselves to obvious market-based policies. For instance, increasing tariffs in response to supply-side market power will only exacerbate the problem in the short run. Policymakers have other alternatives. For instance, R&D investments in electric vehicles, energy efficiency, and enhanced oil recovery technology would decrease wealth transfers and surplus losses by lowering domestic demand and shifting the domestic long-run supply curve out. These types of investments would likely be evaluated based on some form of benefit-cost analysis. Total cost estimates would serve as the benefit of these types of R&D programs.

2. 4. BENCHMARK: CURRENT STATE OF THE WORLD OR FIRST-BEST MARKET OUTCOME

Measuring the costs of oil dependence requires specifying a benchmark. Current estimates of oil dependence cost are predicated on one of two benchmarks: 1) a first-best, perfectly competitive market; 2) the current state of the world given market failures and existing policy. Figure 7 highlights the two benchmarks when the dominant market failure is supply-side market power.

Following the discussion in section 2.1, the major motivation for calculating oil dependence costs is market failures in the oil market. Thus, a natural choice for a benchmark is the first-best, perfectly competitive world oil market absent any market failures. A total cost approach using the perfectly competitive economy as a benchmark would yield an oil dependence cost estimate equal to B+C-A. A premium approach using the perfectly competitive economy as a benchmark would be similar to estimating the change in B, C, and A when oil imports are increased by one barrel.

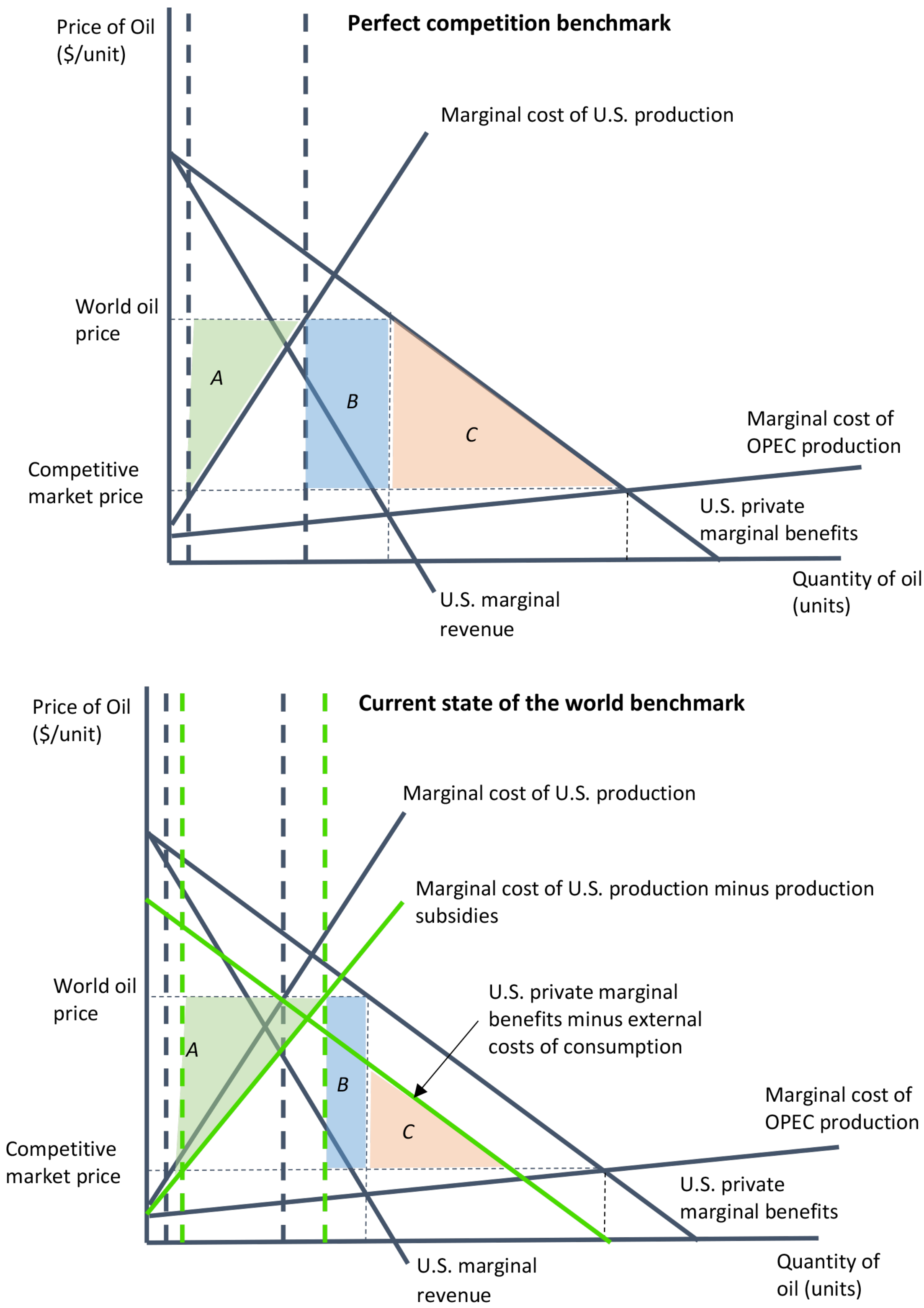

Figure 7. Comparing oil dependence costs associated with cartel pricing using a perfectly competitive economy and the current state of the world as a benchmark

An alternative is to use the current state of the world as the benchmark for analysis. Estimates based on the current state of the world account for existing market failures and energy policies in place. For example, production subsidies may be currently in place to incentivize domestic oil production. This policy would shift the U.S. long-run and short-run supply curves out. There are also unpriced, negative externalities associated with oil consumption that would lower the realized marginal benefits of oil consumption. This existing policy (domestic production subsidies) and market failure would represent deviations from the perfect competition benchmark that lead to different total cost estimates of the domestic surplus losses (area A), wealth transfer to foreign producers (area B), and wealth transfer to domestic producers (area C). Likewise, a premium approach will also lead to different oil dependence costs depending on which benchmark is chosen.

Welfare economic theory does not provide any guidance on which benchmark should be used. However, there are practical matters to consider when evaluating oil dependence costs estimates based on different benchmarks. Estimates that use a first-best economy as a benchmark provide a measure of the *potential* gains from a policy that would reduce oil consumption (either total consumption or imports depending on the scope of the analysis). These types of estimates are useful for highlighting the magnitude of the oil dependence problem since they provide a more comprehensive measure of oil dependence costs. However, these estimates are unlikely to provide an accurate estimate of the actual benefits of a policy that seeks to reduce U.S oil imports since this benchmark does not account for existing policies and other market failures. Using a first-best economy as a benchmark also requires the researcher to identify an unobserved competitive market price absent any market failures (market power and externalities depending on the market failures considered in the analysis). While there are ways to obtain proxies for the competitive world oil price (Greene and Leiby 2006), there is no perfect method for estimating the price of oil if all world producers behaved as competitive suppliers. Further, it is difficult to predict oil prices in the future due to a variety of factors (e.g., technological change, depletion) and virtually impossible to predict prices in a hypothetical perfectly competitive and complete oil market.

Alternatively, a current state of the world benchmark provides a more accurate estimate of the *likely* gains from a policy at a point in time. As a result, a current state of the world benchmark would be the preferred benchmark for ex-post evaluation of policies. However, the oil dependence cost estimates that arise from a current state of the world benchmark will reflect a variety of influences only some of which will be related to oil dependence. Because a current state of the world benchmark filters oil dependence costs through the lens of a variety of policies and market failures, it will not represent the most accurate estimate of oil dependence costs. Using a perfect competition benchmark in conjunction with a current state of the world benchmark gives analysts a more accurate depiction of the costs of oil dependence *and* the benefits of policies intended to alleviate these costs.

2. 5. DYNAMICS: SHORT-RUN VERSUS LONG-RUN EFFECTS

Even when oil dependence cost estimates are based on the same cost components, they may still differ due to the inclusion of oil market dynamics. The most common dynamic adjustment accounted for in oil dependence costs estimates are the short- and long-run elasticities of supply and demand. Elasticities measure responses to prices changes. Several factors deter immediate adjustments to changes in the world oil price. For instance, consumers are unlikely to immediately trade-in a gasoline-powered automobile for an electric automobile following an increase in gasoline prices. However, a sustained period of higher gasoline prices is more likely to trigger a switch to an electric automobile. As a result, short run demand elasticities are typically far smaller than long-run demand elasticities. Similar dynamic adjustments occur on the supply side. U.S. oil producers may not increase production in response to a transitory increase in world oil prices but will increase production in response to a sustained period of higher prices.

Virtually all oil dependence cost estimates account for these differences in short- and long-run elasticities. This difference in short-run and long-run elasticities is a fundamental component of estimates of the potential GDP losses, wealth transfer, monopsony effect and disruption costs. However, the difference between short-run and long-run adjustments causes market power to vary dynamically and causes producer and consumer surplus to vary dynamically as well. These dynamic adjustments to the cost components imply that oil dependence cost estimates should be updated periodically. It also implies that differences in oil dependence costs may arise due to way they aggregate these different costs during normal and disrupted periods. Since supply disruptions are an inherently risky event, one challenge is to combine costs incurred during normal market conditions and costs incurred during supply disruptions. Monte Carlo simulation techniques can be used to incorporate the probability and magnitude of supply disruptions. However, a weighted average of costs during a disruption and during normal periods can lead to erroneous policy conclusions (Bohi and Montgomery 2015).

Other types of dynamic adjustment are less frequently considered in oil dependence cost measures. The Federal Reserve actively adjusts interest rates following an oil price shock. These adjustments influence nearly all of the components of oil dependence costs either directly or indirectly. Few estimates of oil dependence costs account for this type of dynamic adjustment (Bernanke, Gertler et al. 1997).

2. 6. DATA: SOURCES, CALIBRATION, AND UNCERTAINTY

One obvious source of variation in oil dependence cost estimates is in the data used in the analysis and the interpretation of the data necessary for use with models. While there are far too many data sources and assumptions to address each in turn, this section briefly discusses the major data needs and sources that have been used in past estimates.

Any analysis of oil dependence costs relies on few key pieces of information:

- Long- and short-run price elasticity of world oil demand
- Long and short-run price elasticity of Non-OPEC oil supply
- Long and short-run price elasticity of US oil supply
- Frequency, duration and magnitude of oil supply disruptions
- Elasticity of U.S. GDP with respect to oil price shocks
- Future world oil market conditions

Perhaps the most influential component of any oil dependence cost study is the supply and demand elasticities. Elasticity estimates are typically taken from existing studies. Table 2 shows the elasticity assumptions for a selection of oil dependence cost studies. Most estimates of oil dependence costs are based on similar assumptions about the responsiveness of world oil demand. Based on relatively consistent findings from a large number of studies (Atkins and Jazayeri 2004, Brown and Huntington 2010), analysts typically use a short-run price elasticity of world oil demand between -0.04 and -0.08. This range of values is largely explained by whether the analysis accounts for asymmetric price effects (Gately and Huntington 2002). Analysts have also reached a consensus that the long-run elasticity of demand is approximately 5-6 times larger than the short-run demand elasticity. Some variation in elasticity estimates can arise depending on the time frame of the analysis and the country under study (Cooper 2003). There is much less consensus on the responsiveness of world oil supply due to a relative lack of studies that estimate supply elasticities for oil.

Table 2. Elasticity assumptions for base case scenarios in oil dependence cost studies

Price elasticity of oil demand	
Broadman and Hogan (1988)	Long run: -0.5
Leiby, Jones et al. (1997)	Long run: -0.19
Greene and Leiby (2006)	Short run: -0.0377 to -0.05
Leiby (2007)	
Brown and Huntington (2013)	Short run: -0.055
Greene and Liu (2015)	Short run: -0.079
Price elasticity of oil supply	
Broadman and Hogan (1988)	Long run: 0.5
Leiby, Jones et al. (1997)	Long run: 0.6
Greene and Leiby (2006)	Short run: 0.04 to 0.05
Leiby (2007)	
Brown and Huntington (2013)	Short run: 0.05
Greene and Liu (2015)	Short run: 0.1025
Elasticity of U.S. GDP with respect to oil price shocks	
Broadman and Hogan (1988)	-0.05
Leiby, Jones et al. (1997)	
Greene and Leiby (2006)	-0.055
Leiby (2007)	-0.045
Brown and Huntington (2013)	-0.044
Greene and Liu (2015)	-0.055

Analysts must also specify the risk of oil supply shocks. Oil supply disruptions are not certain. Any estimate of oil dependence cost that includes disruption costs will be sensitive to the risk supply shocks. These shocks could arise due to accidents, internal political struggles, international embargos/economic disputes, or wars. Even the simplest accounting for disruption costs would need estimates of the frequency, and duration of supply shocks. Assessments of oil supply disruption risk fall into three categories:

1. Application of statistical techniques to data on historical pattern and frequency of events.
2. Applications of structured expert judgment
3. Explicitly model and analyze source of potential disruption

These methods represent a variety of ways the uncertainties inherent in oil market disruptions can be explicitly represented. The first approach treats oil market disruptions as a quantifiable risk (known unknown) while the second and third approaches recognize that past may not be a good predictor of the future.

The difficulty in quantifying disruption risks and the variety of methods used leads to variation in disruption cost estimates and subsequent estimates of oil dependence costs. During the 1990s, estimates of the risk of oil supply disruptions varied by as much as a factor of five. Many of the more recent estimates of oil dependence costs are based on the risk assessment performed by the Stanford Energy Modeling Forum (EMF) Project on Oil Disruption Risks (Beccue and Huntington 2016). The EMF assessments (performed in 1996, 2005, and 2016) are based on the views of an expert panel and draw on the tools and methodology of structured expert judgement. These expert-based risk assessments are then used to develop probabilistic models that can be used to simulate oil supply shocks. However, transitioning from subjective estimates of risk to probabilistic models requires fitting a continuous probability distribution to the subjective risk estimates. A variety of distribution forms have been selected. The most simple analyses fit the first (mean) and second (variance) moments of the distribution while others account for the third (skewness) and fourth (kurtosis) moments of the distribution. For example, some disruptions costs are estimated based on a lognormal distribution of supply shocks while others use an extreme value or gamma distribution to describe the risk of supply disruption.

Oil supply disruptions fall somewhere between quantifiable risk and deep (Knightian) uncertainty necessitating a combination of approaches. For example, only 18 significant oil supply shock events occurred between 1951 and 2000 (Leiby and Bowman 2000). With so few observations, relying solely on the first approach is unlikely to provide an accurate assessment of future risk. Relying solely on the second approach, leaves the analysis exposed to subjective beliefs of the expert panel which are impossible to validate. The third approach allows for the greatest flexibility in addressing both risk and uncertainty but are limited by the focus on a single or set of potential disruption sources. Analysts view the tradeoffs between forward- and backward-looking risk assessments differently. Some focus on the need to compensate for the relative infrequency of major oil supply shocks by augmenting historic risk estimates with the subjective assessment of the EMF expert panel (e.g., Leiby 2007, Brown and Huntington 2010, Brown and Huntington 2013). Others default to the historical record (e.g., Greene and Leiby 2006).

The models used to generate oil dependence cost estimates have many parameters. Only some of these parameters can be estimated directly based on readily available data. For those parameters where data availability is limited, analysts rely on model calibration. Calibration involves the systematic adjustment of model parameter estimates so that model outputs (e.g., U.S. oil imports, world oil price) more accurately reflect actual benchmarks. The long-term projections provided in EIA's Annual Energy Outlook are commonly used as benchmarks for calibration. How benchmarks are identified from these projections will alter model parameters and the results oil dependence cost estimates. This calibration exercise means that an oil dependence cost estimate is specific to the scenario in which it was calibrated and assumptions concerning what constitutes a realistic or desirable benchmark vary. Oil dependence cost estimates are then validated to determine how well the underlying models represent the system. However, validation of oil dependence costs estimates is typically limited to comparison to previous estimates in the peer-reviewed literature.

Some degree of intra-study variation in oil dependence cost measures can be expected simply due to accounting for various sources of uncertainty. Oil dependence cost estimates are influenced by three main sources of uncertainty (LaRiviere, Kling et al. 2017):

1. Future uncertainty (stochasticity). While world oil supply and demand at any given time are relatively well-known, oil supply and demand in the future cannot be perfectly predicted. Many oil dependence cost estimates account for unexpected shocks to world oil supplies. However, few estimates account for shocks to world oil demand. Those that do focus on supply-side shocks typically focus on specific sources of supply disruptions and assume a stationary distribution. This approach is unable to account for changing technology (e.g., the widespread adoption of natural gas fracking technologies) that would cause the distribution of supply shocks to be nonstationary.

2. Parameter uncertainty: There is often considerable uncertainty about particular parameters in a model. For example, short-run supply elasticities have ranged from 0 to -0.1. Analysts often use consider a range of parameter values to account for this uncertainty. The range selected and the method of accounting for this uncertainty (scenario analysis versus Monte Carlo simulation) will influence oil dependence cost estimates.

3. Model uncertainty: Analysts are also uncertainty about particular aspects of the model such as functional forms, curvature assumptions, and autocorrelation structure. For example, an analyst will not know, a priori, the quantity of imports that will move a market to the backward-bending portion of the supply curve. This type of uncertainty is rarely addressed in the oil dependence cost literature.

Assumptions concerning which uncertainties are accounted for and how can lead to important variation in estimates across studies.

3. MATCHING POLICY CONTEXT WITH THE APPROPRIATE ESTIMATE

To match the appropriate oil dependence cost measure to the appropriate policy context, we propose of two-stage taxonomy:

Stage 1 – Cost components: The first stage addresses the various cost components that arise due to differences in market failures considered and the scope of the analysis. Figure 8 illustrates the cost typology. The typology first distinguishes between pecuniary externalities (changes in the distribution of income that do not affect oil market efficiency) and efficiency losses originating from a variety of market failures commonly cited in the oil dependence cost literature. Pecuniary externalities arise from changes in the terms of trade during stable market conditions due to noncompetitive oil supply (Type 1) and the lack of coordination among U.S. oil consumers (Type 2). Efficiency losses are disaggregated into those originating from market failures in the world oil market (Types 3, 4, 5, and 6) and market failures in other capital and labor markets that create efficiency losses during supply shocks (Types 7, 8, and 9).

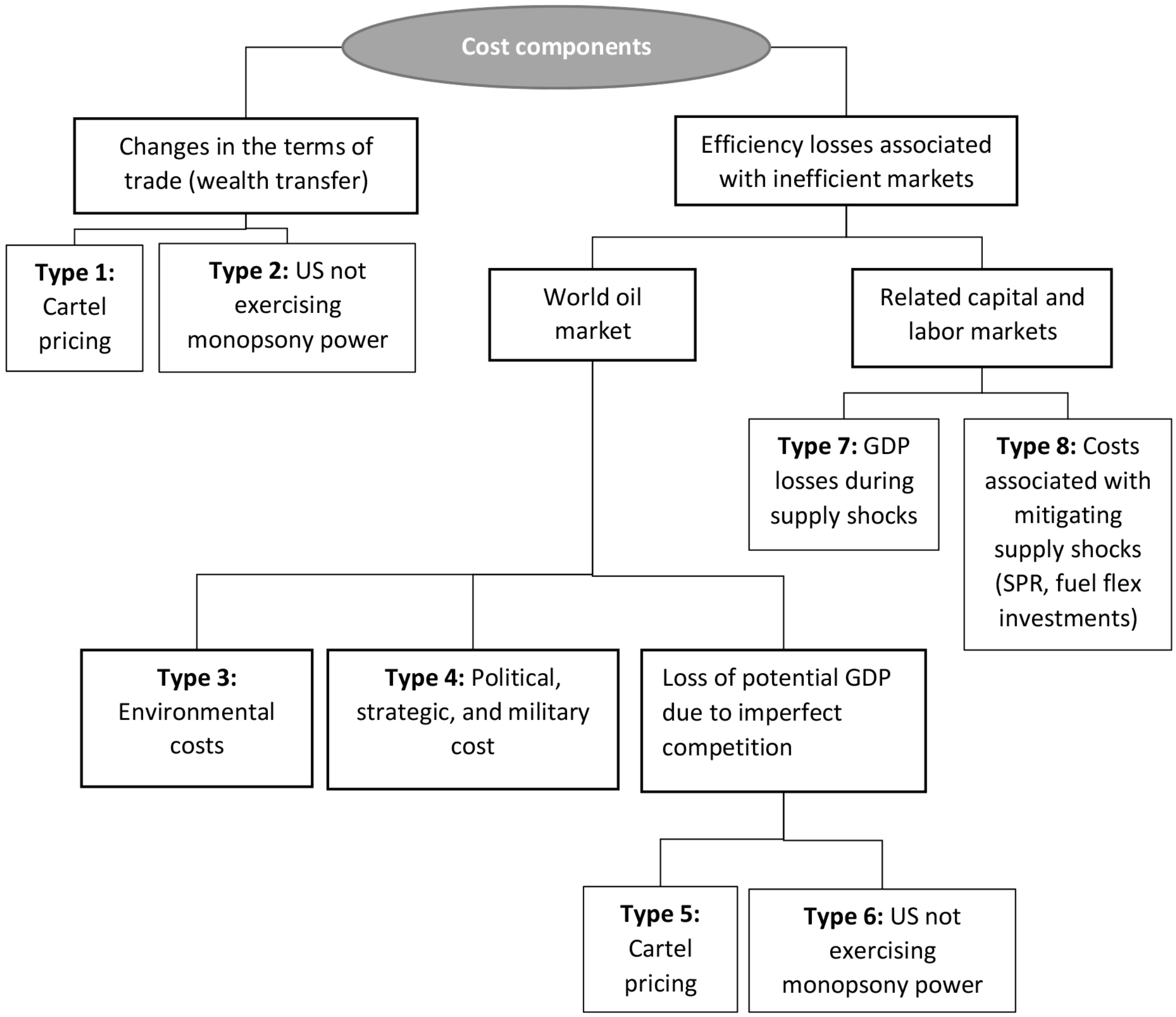

Figure 8. Stage 1 typology for oil dependence cost estimates

Stage 2 - Purpose: The second stage addresses the way the oil dependence cost estimate will be used to inform domestic policy. For example, some oil dependence cost estimate will be used to motivate policy action that has not yet taken place, others will be used to inform the design of a particular policy such as the size of an import tariff, and others will be used to evaluate a policy already in place. These end-use, policy considerations will influence the decision to adopt a premium versus total cost approach and the selection of the appropriate benchmark for analysis. Figure 9 illustrates how these policy considerations lead to four types of oil dependence costs.

		Approach	
		Premium	Total Cost
Benchmark	Current state-of-the-world	**Type A:** Design and evaluate policies that influence the world price of oil	**Type B:** Design and evaluate policies that influence the quantity of oil consumed
	Hypothetical market absent particular market failures	**Type C:** Motivate policies that influence the world price of oil	**Type D:** Motivate policies that influence the quantity of oil consumed

Figure 9. Stage 2 typology of oil dependence cost estimates

According to this two-stage taxonomy, each oil dependence cost estimate is assigned a letter to identify the method used (Figure 9) followed by a series of numbers to identify which cost were included in the estimate (Figure 8). Table 3 provides a list of domestic policy contexts that may be informed by oil dependence costs estimates. For each policy context, we apply the taxonomy to identify appropriate policy scope of the estimate (Stage 1) as well as the purpose of the estimate (Stage 2). Oil dependence cost estimates used in the context of international agreements may also need to consider spillover impacts that may accrue to other nations who are similarly reliant on oil. These spillover impacts are not considered in the stage 1 typology presented in this report.

Table 3. Oil dependence cost taxonomy applied to select energy policies

Policy	Stage 1	Context	Stage 2
Carbon tax	3	Motivate need for carbon tax	C
		Set carbon tax ($/barrel)	A
		Evaluate impact of carbon tax proposal	B
Vehicle fuel efficiency standards	3,5,6	Motivate need for fuel efficiency standards	D
		Set standards	B
		Evaluate impact of fuel efficiency standards	B
Tax on oil consumption	3,5,6	Motivate need to reduce oil consumption	C
		Set oil consumption tax ($/barrel)	A
		Evaluate impact of oil consumption tax	B

Oil import tariff	1,2,5,6	Motivate need for oil import tariff	C
		Set oil import tariff ($/barrel)	A
		Evaluate impact of oil import tariff	B
Tax credits for flex-fuel vehicles	1,2,5,6,7,8	Motivate need for flex-fuel tax credits	D
		Set tax credits for flex-fuel vehicles	B
		Evaluate impact of tax credits on flex-fuel vehicles	B
Domestic oil production subsidy	1,2,5,6,7,8	Motivate need to increase domestic production	C
		Set subsidy for domestic oil production (capital expenditure credits, payroll tax reductions, below cost royalty payments)	A
		Evaluate impact of domestic production subsidy	B
Federal funding for R&D	1,2,3,5,6	Motivate need for public funding that lowers overall energy intensity, encourages long-run energy diversity, and encourages domestic energy production	D
		Set R&D funding allocations	B
Military presence in oil producing country	4	Motivate need for increased military presence in oil producing country	D
Expand strategic petroleum reserve	4,7,8	Motivate need for expanded capacity	D

Ideally, all cost components in Figure 8 would be included in all oil dependence cost estimates. As with any economic analysis, there are tradeoffs between scope and accuracy. Economic models can be designed to capture many of the cost components in Figure 8. Typically, these more expansive models provide less accurate estimates of any single cost component. Due to this tradeoff, cost components must be carefully matched to the policy context. For example, it would be challenging to design an economic model that estimates the proportion of military spending attributable to oil dependence and changes in the terms of trade attributable to cartel pricing. Oil dependence cost estimates developed to inform military spending will naturally focus on Type 4 costs at the expense or exclusion of other cost components. Oil dependence cost estimates designed to inform carbon policy will focus on type 3 costs and may exclude type 4, 7, and 8 costs. A cost estimate designed to inform concerning flex fuel vehicles or domestic production should account for types 7 and 8 since a large motivation for these policies is to counter unexpected supply disruptions. However, types 7 and 8 may be less critical for informing fuel efficiency standards.

Hypothetical world oil markets (Type C and D) are generally the preferred benchmark when motivating the need for a particular policy. These measures provide an indication of the potential benefits of reducing oil imports that are more appropriate for framing questions about the need for policy action. In contrast, a current-state-of-the-world benchmark (Type A and B) is preferred for designing and evaluating policies since these measures provide a more accurate measure of the impacts that will actually be experienced when the policy is enacted. Selecting the estimation approach will depend on the policy being considered. Policies that focus on influencing the price of world oil (carbon tax, import tariff, oi consumption tax) will require a premium approach (Type A and C). Policies that focus on altering the quantity of world oil imported (Vehicle fuel efficiency standards, tax credits for flex-fuel vehicles) will require a total cost approach (Type B and D).

4. EXAMPLE: OIL SECURITY METRICS MODEL & OIL IMPORT PREMIUMS

In this section, we compare and contrast two oil dependence cost measures using the analysis in section 2 and the typology developed in section 3. The first oil dependence costs measure is produced from the Oil Security Metrics Model (Greene and Leiby 2006). The second oil dependence cost measure is the oil import premium developed by Leiby, Jones et al. (1997) and updated in Leiby (2007). These two oil dependence costs measures differ in a number of respects (detailed below) but are designed to achieve many of the same goals for an oil dependence cost estimate. This comparison is intended to achieve two goals. First, applying the typology to actual oil dependence cost estimates is the best way to illustrate the concepts highlighted in section 2 and the utility of the typology developed in section 3. This exercise also uncovers relative strength and weaknesses of the two approaches.

4. 1. OIL SECURITY METRICS MODEL

The Oil Security Metrics Model (OSMM), developed by ORNL, estimates the costs of U.S. oil dependence and conversely the benefits of reduced oil dependence due to technological innovation and policies (Greene and Leiby 2006). The model has two major components. The first is a four-equation model of the world oil market. Linear, lagged adjustment equations are used to represent U.S. oil demand, rest of world oil demand, U.S. oil supply, and rest-of-world, non-OPEC oil supply. The model self-calibrates key parameters such as price coefficients based on four alternative U.S. EIA AEO projections of oil demand, supply and prices. The self-calibration aspect of the model ensures that key parameters such as coefficients are easily updated to reflect current conditions. For instance, studies indicate that the oil supply and demand have become more inelastic between 1980 and 2010 (e.g., Dargay and Gately 2010) while more recent studies suggest hydraulic fracturing technology has reversed this trend. This first component calculates potential GDP loses from U.S. oil dependence with uninterrupted or "business as usual" production by OPEC by decomposing the long-run AEO projections into 1) U.S. oil demand, 2) U.S. oil supply, 3) rest-of-world oil demand, and 4) rest-of-world oil supply assuming.

This four-equation model would be unable to account for GDP losses that occur during supply shocks without a process to generate shocks. Unexpected changes in OPEC oil supply (and the resulting price shocks) are incorporated by means of a stochastic model calibrated to the frequency and size of historical deviations of OPEC production from AEO projections. The probability of an OPEC supply shock, the size of a shock, and its duration are random variables whose distributions have been calibrated to the historical record. While OSMM does not model the OPEC supply explicitly, it does account for stylized aspects of OPEC supply behavior. For instance, shocks are serially correlated to capture the gradual increase in production following a large supply shock that results as OPEC attempts to reclaim market share that was lost during the supply disruption.

For every iteration, the OSMM calculates three measures of the cost of oil dependence in comparison to a hypothetical competitive world oil market:

1. Loss of potential GDP due to higher than competitive market prices. This is typically the smallest component of oil dependence costs
2. Dislocation (temporary) losses of GDP due to oil price shocks. This is typically the second largest component of U.S. oil dependence costs.
3. Transfer of wealth from U.S. to oil exporting countries due to monopoly pricing and price shocks. Unlike the first two components of oil dependence costs, the wealth transfer is not loss of GDP just a change in ownership. The wealth transfer is the largest component of the OSMM's estimate of oil dependence costs but also relies on estimating a counterfactual competitive world oil price.

The sum of these three measures provides an estimate of the total cost of oil dependence. Multiple iterations are performed in order to generate distributions of future oil dependence costs for each year of the forecast.

4. 2. LEIBY'S OIL IMPORT PREMIUM

In contrast to the OSMM model described above, the oil import premium developed by Leiby, Jones et al. (1997) and updated in Leiby (2007) estimates the *marginal* benefits to society, in dollars per barrel, of reducing U.S. oil imports. More specifically, "[the] oil premium is not a measure of the full social costs of oil imports, or the full magnitude of the oil dependence and security problem. Rather, it is a measure of the quantifiable per-barrel economic costs that the US could avoid by small-to-moderate reduction in oil imports" and "…it is most consistent with the benefits of contracting domestic demand or expanding domestic supply along the existing demand and supply curves through conventional market incentives". Like OSMM, the oil import premium does not account for environmental costs (type 3) or political, strategic, and military costs (type 4).

The model begins with a functional description of how U.S. economic net benefits N are influenced by the level of oil imports q_i:

$$N(q_i) = P_i(q_i)q_i - P_w(q_i)q_i - E\left[C(q_i)\right]$$

where $P_i(q_i)$ is the price U.S. consumers would be willing to pay for oil, $P_w(q_i)$ is the direct marginal cost of imports (the world price of oil), and $C(q_i)$ is the expected costs associated with oil market shocks. The marginal net benefit from a change in imports is then:

$$\frac{\partial N(q_i)}{\partial q_i} = \underbrace{P_i(q_i) - P_w(q_i)}_{\substack{\text{marginal private net} \\ \text{benefit of oil imports}}} - \underbrace{\left(q_i \frac{\partial P_w}{\partial q_i} + \frac{\partial E\left[C\right]}{\partial q_i} \right)}_{\substack{\text{marginal social cost} \\ \text{of oil imports}}}$$

The oil import premium is defined as the difference between the marginal private net benefit of oil imports and the marginal social net benefit of oil imports:

$$\pi(q_i) = P_i(q_i) - P_w(q_i) - \frac{\partial N(q_i)}{\partial q_i} = \underbrace{q_i \frac{\partial P_w}{\partial q_i}}_{\substack{\text{monopsony} \\ \text{premium}}} + \underbrace{\frac{\partial E\left[C\right]}{\partial q_i}}_{\substack{\text{disruption} \\ \text{premium}}}$$

The oil import premium will be positive provided the world oil supply curve is upward sloping. A negative oil import premium can arise if the world oil supply is backward bending. This is most likely to arise when some major oil producing countries (those where oil revenues are a large proportion of GNP) are reluctant to absorb excess revenues through increased consumption (Bohi and Montgomery 2015).

The oil import premium has two components. The first is the monopsony premium, which captures the effect of a sustained change in oil imports on the equilibrium world oil price. The second is the disruption premium, which accounts for the change in expected short-run losses during transitory disruptions. Note that it is impossible to determine how the oil import premium changes with the level of oil imports without imposing assumptions on the curvature of the oil supply function and the disruption cost function.

4. 3. COMPARING THE TWO APPROACHES

The two approaches are compared and contrasted in Table 4. From an economic perspective, both methods are conceptually correct as both are modeled within a standard welfare economic theoretical framework. The two methods are also similar in other respects. Both estimates are influenced by similar determinants and drivers: OPEC supply behavior; demand behavior of other importers; disruption probabilities; availability of oil stocks and excess capacity to put more oil onto the market during an oil supply disruption; responsiveness of oil consumers to price shocks; consumers anticipation of and preparation for oil price shocks; sensitivity of economic activity to oil shocks. Both estimates also omit military, climate, and regional pollution considerations. Both estimates also use many of the same data sources although the interpretation of this data may vary. Given these similarities and a consistent grounding in welfare economic theory, we conclude that both estimates are useful and potentially appropriate for informing policy. However, there are important differences between the measures.

The oil import premium has a taxonomic classification of A:12567. The A in the classification signifies that this estimate takes a marginal cost approach and uses the current-state-of-the-world as a benchmark for analysis. The numbers in the classification signify that it captures cost types 1, 2, 5, 6, and 7 (see Figure 8). This classification suggests the oil import premium would be useful in the following policy contexts:

- Set oil consumption tax ($/barrel)
- Set oil import tariff ($/barrel)
- Set subsidy for domestic oil production (capital expenditure credits, payroll tax reductions, below cost royalty payments)

This does not imply that the oil import premium is useless in other policy settings. It may still help motivate the economic case to reduce overall oil consumption or the need to increase domestic oil production. However, it is not designed to specifically answer these questions and would need to be modified or used in conjunction with other measures. Because it takes a marginal cost approach and uses the current state-of-the-world as a benchmark (type A), it is not well-suited to inform type D policy issues such as motivating the need for fuel efficiency standards, expanding the capacity of the SPR, or flex-fuel tax credits.

The OSMM-based estimate has a taxonomic classification of D:12567. The D in the classification signifies that this estimate takes a total cost approach and uses the hypothetical Pareto-optimal world oil market as a benchmark for analysis. The numbers in the classification signify that it captures cost types 1, 5, and 7 (see Figure 8). The OSMM-based estimate includes the monopsony effect (type 2 and 6) by simulating the world oil market response to changes in U.S. imports. While the most recent oil import premium estimates the monopsony effect at $8.9/bbl, there are several reasons to believe the monopsony effect may be much smaller than existing estimates (including the oil import premium) suggest. This classification suggests the OSMM-based estimate would be useful in policy contexts in which the oil import premium is not well-suited:

- Motivate need for fuel efficiency standards
- Motivate need for flex-fuel tax credits
- Motivate need for public funding that lowers overall energy intensity, encourages long-run energy diversity, and encourages domestic energy production
- Motivate need for increased military presence in oil producing country
- Motivate need for expanded capacity

However, the largest component of the OSMM-based estimate is the wealth transfer from U.S. consumers to foreign producers due to supply-side market power. Estimating this component relies on establishing the oil price in a hypothetical competitive world oil market. Establishing this price is challenging and essentially prevents any validation of this estimate against real-world data. The OSMM-based estimate is also not designed to address policy issues that the oil import premium is designed to address. Used in conjunction, the oil import premium and OSMM can provide estimates of oil dependence costs that are useful and appropriate in a wide variety of contexts.

Table 4. Comparing an oil import premium and a total cost approach

	Oil Import Premium	OSMM
Taxonomic classification	A:12567	D:12567
Approach	Marginal social cost analysis. Could be interpreted as 1) the costs of imported oil not captured in the price of imported oil or 2) society's willingness to pay to achieve a small reduction in oil imports.	Total costs of oil dependence compared to a contrary to fact competitive world oil market.
Premises	Market does not fully internalize costs of oil demand or oil market disruptions. As a result, U.S. consumers consume too much imported oil and should be willing to pay to reduce imports.	OPEC cartel (imperfectly) uses market power to raise prices above competitive market levels.
Benchmark	Current level of oil imports given market failures and existing policy. Benefit estimates represent marginal improvements from the current state of the world.	Counterfactual competitive world oil market (no market supply-side market power) with no policy intervention. Benefit estimates represent all cost that could potentially be avoided.
Cost components	Impacts of oil market disruptions on GDP and monopsony benefits of reduced U.S. oil imports. Inclusion of monopsony effect justified by market power of oil exporters. Marginal impact of oil importation limited to the following impacts on economy: 1. Demand costs or monopsony effect, 2. Higher cost of oil imports and wealth transfer during shocks, 3. marginal change in GDP losses during supply disruptions. Excludes environmental and national defense effects.	Limited to direct economic costs (excludes environmental and national defense effects): 1. Potential GDP losses (producer and consumer surplus losses) from a price increase, 2. Temporary GDP losses due to oil price shocks, 3. Wealth transfer from importers to exporters due to monopolistic pricing of oil.

Market dynamics	Short- and long-run adjustments dynamics built into supply and demand equations but oil dependence costs are not dynamic. One component of the oil import premium (the monopsony premium) captures the long-run impacts and another component (the disruption premium) accounts for the short-run impacts on the premium.	Changes in market power and surplus measures (consumer and producer) accounted for through Monte Carlo simulation.
Data	AEO-2006 Base oil market projections, OPEC supply response elasticity, domestic long-run supply and demand elasticity Supply disruption probabilities taken from 2005 EMF survey	EIA AEO world oil market High, Reference and Low world oil price projections reflect meaningful range of possible oil market futures. Oil price elasticities of supply and demand, adjustment rates and probabilities of market disruptions based on literature review.
Calibration/validation	Self-calibrates to EIA AEO projections. Validation by comparison to previous estimates in the peer-reviewed literature.	Self-calibrates to EIA AEO projections. Limited validation by comparison to macroeconomic cost estimates in the peer-reviewed literature.
Uncertainty	Future uncertainty addressed through stationary distribution of supply disruptions. Probability distributions are based on a combination of expert judgment and historical record. Uncertainties about key parameters addressed by considering a range of values. No adjustment for model uncertainty.	Monte Carlo simulation of alternative oil market scenarios to capture uncertainty about future market conditions (exogenous supply and demand shocks) and uncertainties about key parameters. Probability distributions are based on the historical record of supply shocks. No adjustment for model uncertainty.

Interpretation	Estimate value of marginal reductions in oil imports. Estimate optimal tariff on imported oil.	Estimate change in total costs of oil dependence due to reduced U.S. petroleum demand or increased U.S. petroleum supply or alternative world oil market scenarios. Measure some benefits (see cost components above) of both oil import reduction and oil consumption reduction.
Application	Applicable for evaluating policies that trigger a small change in oil imports.	Applicable for evaluating policies that trigger both large or small changes in oil use as well as drastic changes in technology.
Key findings	Significant oil dependency costs but these costs have decreased in recent years	Significant oil dependency costs but these costs have decreased in recent years

* For policy evaluation, these benefits of oil import reductions must be compared to the cost of reducing imports.

5. FUTURE WORK TO IMPROVE OIL DEPENDENCE COST MEASURES

This report highlights the various ways that oil dependence cost estimates may differ. Critics interpret the inability to reach a consensus estimate of the costs of oil dependence as a sign that these estimates are imprecise. This report highlights numerous reasons that such a conclusion would be false. However, it would also be false to conclude that additional work to improve these estimates is not needed. Considerable effort has been devoted to improving estimates of supply and demand elasticities and these efforts should continue given the influence of these parameters on oil dependence cost measures. Below we highlight five areas where we feel future work is needed in the analysis of oil dependence cost estimates:

1. ***Design a universal metric for comparing oil dependence cost estimates.*** For example, one could convert the oil import cost estimate into a total cost estimate that could be more directly compared to the total costs from the OSMM (or alternatively, compare the per barrel costs from OSMM to the import premium). Since total cost

and marginal cost approaches each have their advantages and disadvantage, it is important to understand when they yield similar oil dependence cost estimates.

A greater emphasis on assessing the validity of individual components of oil dependence cost estimates. As this report illustrates, existing oil dependence cost estimates differ on many dimensions. One implication of this finding is that identifying an indicator or set of indicators to assess the validity of these composite estimates is challenging. One way to sidestep this challenge would be to assess the criterion validity of individual components of the oil dependence cost estimates using readily available metrics that are not inputs in the modeling activity. For example, time series data on OPEC market share could be used to assess the validity of wealth transfer estimates. Since market share signals greater market power, we should expected periods with higher OPEC market share to be positively correlated with wealth transfer estimates (perhaps with a reasonable lag).

Another example would be to compare the oil futures and spot prices to assess validity of disruption cost estimates. Disruption costs are one of the most challenging elements of oil dependence costs to estimate. One challenge to testing the validity of disruption cost estimates is the need to determine how much market participants anticipated a given supply shock. If market participants anticipate a supply shock due to emerging geopolitical conflict, they will take actions to mitigate the effect of the supply shock. Unanticipated supply shocks should be larger than anticipated supply shocks all else equal. One possible approach to capture the degree to which supply shocks were anticipated is to compare oil futures and spot prices. Under normal world oil market conditions, futures prices for oil exceed the spot price due to storage costs for holding the oil and other forgone opportunity costs such as interest (i.e., holding costs). In an inverted market, the spot price exceeds the futures price. Since the futures price fails to cover the holding costs, storing oil apparently implies negative returns. An inverted market arises due to unexpected supply shortages leading to what is known as a convenience yield. We should expect disruption costs to be larger during inverted market periods since these periods tend to signal large unexpected oil supply shocks. One way to test the validity of the disruption cost component of oil dependence costs is to test for a negative relationship between disruption costs and the futures spread (i.e., the difference between futures price and the spot price). Figure 10 shows the correlation between the disruption (adjustments) cost estimates from OSMM (with AEO 2014 basecase projections) and the oil futures spread. Larger disruption cost estimates tend to be correlated with more normal market conditions even when accounting for a one-year lag in the OSMM estimates. Clearly there are other explanatory factors (magnitude and duration of shock, type of shock, stock market returns) that need to be controlled for to fully assess this relationship. However, the process of benchmarking individual cost components against theoretically consistent economic metrics will provide a more precise definition of these cost components and shed light on their validity.

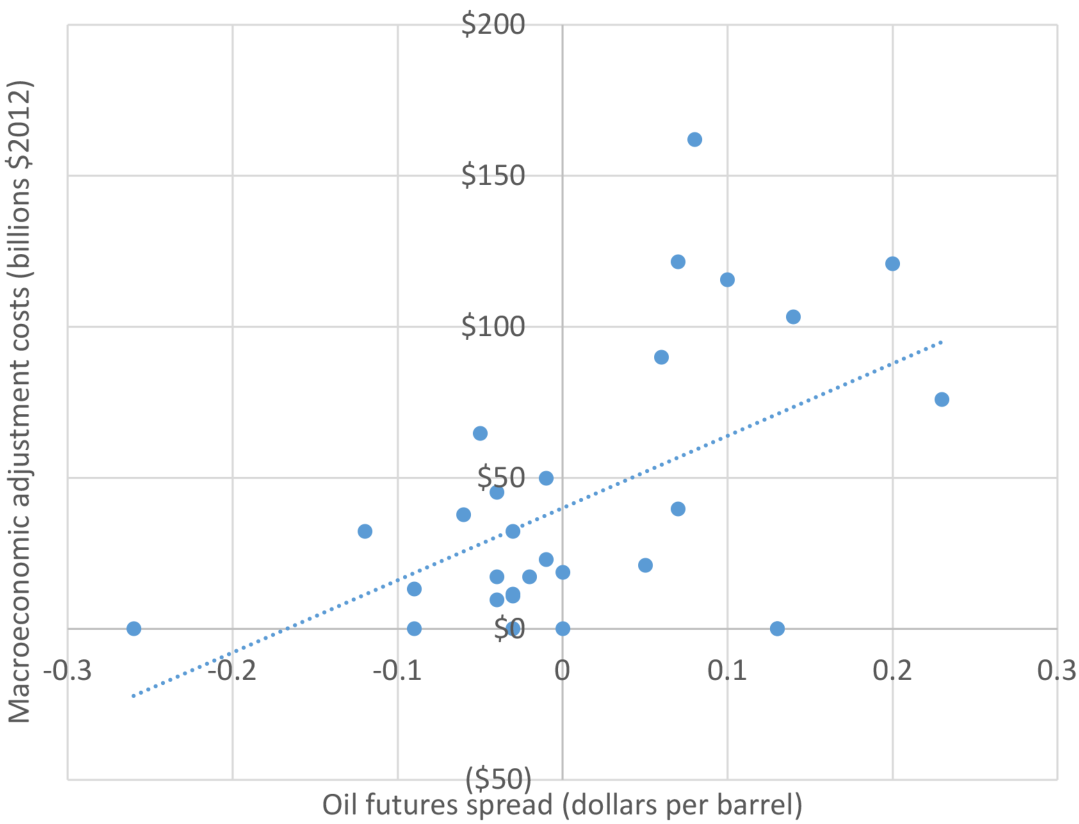

Figure 10. Relationship between oil market futures spread and disruption costs (adjustments costs) produced from OSMM using AEO 2014 basecase projections

2. ***A global sensitivity analysis would provide a clearer depiction of the sensitivity of oil dependence cost estimates to the unavoidable parameter uncertainty that arises in models of the world oil market.*** All methods of estimating oil dependence costs are based on large, complicated models of the world oil market. Implementing these models necessitates estimating a large number of parameters. For some parameters, readily available data allows researchers to arrive at a parameter value with great confidence. However, relevant data is often missing or incomplete for many if not most of these parameters leading to considerable uncertainty over the appropriate parameter value to use in the analysis. It is standard to perform a sensitivity analysis whereby oil dependence cost are estimated when highly uncertain parameter values are varied by some pre-determined amount. For example, many analyses will present a low, medium, and high estimate of oil dependence costs to capture this parameter uncertainty. However, sensitivity analysis is typically performed in piecemeal whereby parameters values are varied one-by-one. This effectively assumes that only one parameter is uncertain. In reality, multiple parameters are uncertain. For instance, standard approaches to conduct sensitivity analysis would be unable to determine how a 5 percent change in the price elasticity of oil demand influences oil dependence cost estimates when the price elasticity of oil supply also differs by 5 percent. Latin hypercube sampling (McKay, Beckman et al. 1979) and partial rank correlation coefficients could be used to determine the parameters in model of the world oil market which have a statistically significant impact on the value of the oil dependence costs.

3. ***Additional research is needed to determine how the wealth transfer component of oil dependence costs are affected by the resource rent proxy used.*** The wealth transfer component of oil dependence costs relies on distinguishing between competitive market resource rents and monopolistic resource rents. However, data on resource rents are nonexistent since rents do not show up directly in market transactions. Analysts typically address this issue by treating the world oil price as a proxy for rent. However, the price of oil is often a poor proxy for resource rent even

in competitive markets. Other potential proxies for resource rent such as the marginal cost of discovering new oil reserves have been shown to be a better proxy for the resource rent (Devarajan and Fisher 1982, Farzin 1992). However, the marginal cost of discovering new oil reserves can vary significantly between competitive markets and monopoly (Adelman 1990) suggesting that the difference between competitive and monopoly resource rents will differ depending on the resource rent proxy used.

4. ***Nonconvex production and consumption sets should integrated into models to determine how oil dependence costs are influenced by backward-bending supply curves.*** Nearly all estimates of oil dependence costs assume simple (typically linear) specifications for oil supply and demand functions. These simple functional specifications are common but implicitly assume convex production and consumption sets in which the world oil market is defined by a single market equilibrium. This common specification ignores the possibility of a backward bending supply curve. A backward-bending supply curve is most likely to arise when some major oil producing countries (those where oil revenues are a large proportion of GNP) are reluctant to absorb excess revenues through increased consumption (Bohi and Montgomery 2015). More work is needed to incorporate the confluence of factors that give rise to a backward bending supply curve since it allows for the possibility that oil dependence costs may be negative.

6. CONCLUSIONS

Much like the oft-cited value of statistical life estimates (Viscusi and Aldy 2003), oil dependence cost estimates can vary due to a number of factors. This variation is a natural by-product of the models used to assess oil dependence and the lack of a clear definition of oil dependence. It is also unlikely that a single measure of oil dependence costs would be desirable in all the policy contexts in which these estimates are used (ranging from decisions about environmental policy, international trade policy, and policies concerning national defense). Fundamental modeling tradeoffs suggest that increases in accuracy for certain cost components will only be achieved by simplifying treatments of other cost components. Thus, a measure that strives to improve the accuracy of wealth transfer estimates use in designing tariffs would likely be less accurate in estimating disruption costs.

In summary, there are pros and cons to all current estimates of oil dependence costs. Comparisons can be viewed along two dimensions: cost components and purpose of use. We would discourage attempts to develop a single metric and instead encourage efforts to clarify the conditions under which specific oil dependence costs estimates should be used to inform decision-making. This report develops a taxonomy that could be taken to improve the match between oil dependence costs and policymaking. The report also details several steps that could be taken to better assess the validity of current oil dependence cost estimates. Assessing the validity of individual cost components as opposed to the aggregate cost estimates provide a more promising path forward. We would also encourage efforts to use multiple estimates in concert to inform policy-making as opposed to selecting a "best" estimate. For example, Leiby's oil import premium and the OSMM-based estimate have a number of limitations individually, but are appropriate and useful for informing a wide variety of policy decisions when used in together.

Given the importance of oil to the U.S. economy, calls to assess the full costs of importing foreign oil are unlikely to wane. In fact, rapidly changing world oil markets and an emerging domestic oil industry will put greater pressure on revising old energy policies and developing new ones. Oil dependence cost estimates will undoubtedly be at the center of these debates. Greater care in the use of existing oil dependence costs estimates will improve the outcome of these debates.

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