ESSAYS ON OIL, ENERGY, AND OIL SELF-SUFFICIENCY IN THE U.S.

A Dissertation

by

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ABSTRACT

When oil prices rise, politicians often call for improvements in energy efficiency or policies that they hope will make the U.S. more "energy independent." The argument is that if we consume less oil, domestic supplies will constitute a larger portion of U.S. quantity demanded, mitigating our dependence on potentially unreliable foreign oil sources, thereby lessening U.S. exposure to volatile supply/price fluctuations. Three interrelated issues are addressed in this dissertation. First, the drivers and substitution patterns in U.S. oil demand are explored using structural demand system analysis for energy in the U.S. Second, world oil supply is estimated using the cost structure of world oil reservoirs, which principally depend on reservoir characteristics. Models of both supply and demand yield insight into the feasibility and unintended outcomes of policies or technological advances that reduce oil demand. Finally, the U.S. autarky equilibrium price at the intersection of the U.S. supply and demand curves is considered. Inferences on the economic feasibility for the U.S. to strive towards self-sufficiency in oil are examined including the vulnerability premium associated with national security concerns.

The demand model demonstrates that U.S. oil demand is explained as a system of demands for energy, where individuals are committed in the short run to minimum quantities of consumption. In the context of pre-commitments, oil is found to have a higher own-price elasticity (more elastic) at average than is commonly found in the

literature. Oil is further demonstrated to be a compliment for natural gas and electricity, and a substitute for coal.

Oil production costs and quantities are heavily dependent upon reservoir geology, which has a fixed dispersion around the world. Using this premise, a supply curve composed of world oil reservoirs is generated. Scenario analysis on different world oil demand reductions suggests there are unintended costs of reducing oil demand. Oil producing countries will experience smaller gross domestic products from diminished oil production. Smaller gross domestic products may affect the countries' political stability.

The world oil supply curve and cross price elasticities from the demand model are considered together under the most likely scenario of a fall in world oil demand stemming from a 2.5% decrease in U.S. oil demand. These results are used to consider unintended consequences of changes in U.S. oil demand in attempts to achieve or pursue "energy independence." These results include the impact on coal, natural gas, and electricity demand; the required change in gasoline demand that could precipitate a 2.5% change in oil demand; the change in U.S. GDP; the change in U.S. "energy independence" and; the change in political stability of oil producing nations.

U.S. supply and demand curves for oil will not intersect in the short run with current technology. The implication is that the vulnerability premium for oil would need to be infinite to justify U.S. self-sufficiency in oil. The U.S., therefore, should not strive towards energy independence in oil.

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NOMENCLATURE

AIC	Akaiki Information Criteria
AIDS	Almost Ideal Demand System
BIC	Bayesian Information Criteria
BOE	Barrel of Oil Equivalent
CAFÉ	Corporate Average Fuel Economy
CIA	Central Intelligence Agency
DOE	Department of Energy
EIA	Energy Information Administration
GAIDS	Generalized Almost Ideal Demand System
GDP	Gross Domestic Product
LA/AI	Linear Approximate Almost Ideal Demand System
LA/GAI	Linear Approximate Generalized Almost Ideal Demand System
LR	Likelihood Ratio
OPEC	Organization of Petroleum Exporting Countries
UAE	United Arab Emirates
USD	United States Dollar

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CHAPTER I

INTRODUCTION AND OBJECTIVES

In recent years, as crude oil (henceforth oil) and gasoline prices have increased rapidly, arguments similar to those popular during the 1970's gas price increases have arisen. Again, there are calls for both increased exploration and production activities domestically and policies that will decrease U.S. gasoline and oil consumption. Increasing domestic production, if possible, will clearly increase the ratio of domestically produced oil to imported oil that the U.S. consumes. Arguments for policies that reduce domestic consumption, however, hinge on the hope that with the reduction, U.S. demand can be satisfied by domestic sources (Bengston, 2011; Richardson, 2009; Stephen, 2007). The argument is that by increasing the proportion of quantity demanded met by domestic sources, the influence of cartels and politically unstable oil producing nations that threaten U.S. national security and contribute to a tumultuous world oil market may be reduced.

Whether or not such policies will be effective in achieving the desired result is questionable; determining their efficacy promises to be challenging. The challenge is daunting because of the importance of petroleum products in virtually every aspect of society. Energy drives the economy. Energy prices, therefore, influence economic growth (Ayres et al., 2007). With energy acting as an input in every stage of production, policy changes that alter energy consumption through taxes or mandatory reductions will inevitably initiate repercussions throughout the economy.

Though every ramification of a policy that would reduce oil consumption is indeterminable, insights can be gained regarding the efficacy of such policies in achieving the desired result. Both demand and supply must be considered in modeling market outcomes. It is the intersection of supply and demand, after all, that determines the equilibrium price and quantity after any shift in demand. To determine demand side changes, demand must be modeled not only for oil, but also for its substitutes and compliments, allowing substitution patterns to be explored. Changes in supply are also crucial to the overall impact of a policy, because the shutdown or withdrawal of any U.S. production necessitates additional U.S. demand reduction for foreign oil dependence to wane. Supply must reflect regional eccentricities, to determine the changes in the supply balance that might occur if the U.S. reduces its demand.

1.1. Objectives

Providing insights into oil and energy demand and supply based on "more realistic" assumptions of human behavior associated with demand for oil; physical characteristics of oil production; and demand and supply curve characterizations than used in previous studies is the objective of this study. To achieve this objective, three different aspects of oil supply and demand are examined. Each aspect has its own sub-objective(s) and model.

First, U.S. demand for oil is estimated under the assumptions of pre-commitments and a system of demands that includes multiple energy commodities. Pre-commitment levels are the quantity of a good that is demanded in the short run with little regard for price because of prior commitments to either meet production or consumption requirements. The sub-objective is to examine how accounting for pre-commitment levels influences the energy commodity demand system.

The second aspect's sub-objective is to examine the effect of policies that are directed towards reducing world oil demand. Under the assumption that the physical reservoir characteristics are the primary factors influencing the cost of oil production, a world oil supply curve is developed. Different policy scenarios of world and U.S. reduction in demand are examined in terms of the effect on each country's quantity supplied of oil and gross domestic product.

Finally, using the demand model and the U.S. component of the world supply model, the feasibility of the U.S. becoming oil self-sufficient or independent is examined. The sub-objective is to provide information on the U.S. equilibrium price to help determine if the U.S. should be self-sufficient in oil production.

CHAPTER II

U.S. CRUDE OIL DEMAND WITH PRE-COMMITMENTS

Oil and its derivatives, such as gasoline, have a strong influence on the economies of industrialized countries. What makes these commodities uniquely influential has to do with the capital and products that depend on them. Oil derivatives are virtually without substitutes in their many roles including powering and lubricating internal combustion engines. It is reasonable to expect the own-price elasticity of oil to be highly inelastic. Elasticities are highly inelastic because internal combustion engines and other oil dependent capital are expensive and are purchased in advance by industry and individuals to produce certain short run levels of output. It, therefore, stands to reason that oil demand, at least in the short run, would be highly inelastic.

Highly inelastic short run own-price elasticities for oil are consistently found in the literature (Cooper, 2003; Gately and Huntington, 2002; Krichene, 2002). Inelastic own price elasticities imply that price increases have little impact on quantity demanded in the short run. None of these papers, however, have studied demand for oil as a commodity within a system of demand for energy with pre-commitment levels. Pre-commitments are defined as the quantity of a good that is demanded in the short run with little regard for price; demand is virtually perfectly inelastic. If individuals have committed to consume a given quantity of oil then the price of oil will have little effect over this portion of the demand curve. Over the committed portion of demand, oil can be treated as non-discretionary with correspondingly very inelastic price elasticity. Once pre-commitments have been satisfied price variations have a larger impact on quantity demanded. This portion of the demand curve can be thought of as discretionary (for example, purchasing a tank of gas to go on vacation).

The demand for oil, therefore, may be more accurately modeled by considering pre-commitment levels. Relative to elasticity estimates that do not control for pre-commitment levels (henceforth, referred to as contract levels) own-price elasticity estimates should be larger in absolute value (more elastic) by including contract levels. To understand the logic behind this assertion, assume demand can be broken into two components: contract level consumption (having elasticity near zero) and discretionary consumption. Ignoring these two components during estimation would result in an elasticity measure that is a weighted average of the two components. A weighted average of both components misrepresents both components with an elasticity measure that is too large in the contract portion of the demand curve and too small for the discretionary portion. If the U.S. operates predominately in the discretionary portion of the demand curve (meaning that contract levels have been satisfied), ignoring contract levels will lead to an elasticity measure that is too inelastic.

A more inelastic measure implies that consumers are less responsive to price changes. Such an implication may influence policy that is aimed at energy and crude oil consumption. If consumers are modeled as being less responsive to price changes than they actually are, then policy aimed at curtailing oil consumption would necessitate raising prices to higher levels than necessary to achieve the policy's goal. The converse is also true. With a contract level scenario, own price elasticities are more elastic in the discretionary portion, but much less elastic near the contract level boundary (nearly perfectly inelastic). Raising the price of a nearly perfectly inelastic good does not do much to curtail quantity demanded. Instead, consumption remains nearly the same. Assumptions concerning contract levels, therefore, may have an impact on demand system estimation, as well as, a more practical impact on policy. Oil demand for the U.S. is estimated via the Generalized Almost Ideal (GAI) Demand System (Bollino, 1987) to discover contract quantities and estimate demand elasticities over the discretionary portion of demand.

Similar pre-commitment arguments can be made for the other primary energy commodities in the energy system of the U.S, which are natural gas, coal, and electricity. By modeling as a system, the effect of pre-commitments on the elasticities for these commodities can also be ascertained.

2.1. Objective

The objective is to examine how accounting for pre-commitment levels influences the energy commodity system. Differences between a demand model system with pre-commitments and one without are compared. Differences considered include significance of the coefficients, shape of the demand curve, and price and wealth elasticities that result under the two specifications. In addition, the estimated elasticities are compared to estimates from the literature. To accomplish this objective, a system of demands for energy that includes oil, coal, natural gas, and electricity is estimated. The estimation takes two forms: the Generalized Almost Ideal Demand System (GAIDS or GAI for short), which endogenously estimates pre-commitment levels and the Almost

Ideal Demand System (AIDS or AI), which does not explicitly consider contract levels for comparison.

2.2. Literature Review

Models have been developed to quantify and predict both U.S. and world oil demand. Although the specific approaches vary, the vast majority of models fall into the category of the lagged endogenous models, which posit oil demand as a linear or log linear function of wealth and indexes of price and lagged prices (Dahl and Sterner, 1991). The current and lagged price structures allow both short and long run price elasticities to be estimated. In most cases, the short run is the marginal effect of current price, while the long run is the marginal effect of the lagged price. Dahl and Sterner (1991) in their review of over 100 studies, find that of the studies they surveyed, the average short run own price elasticity of gasoline is -0.26 and the long run own price elasticity is -0.86. Implications of these elasticities are that the past price has a larger impact on quantity demanded than the current price and that purchasing habits are slow to adjust to price changes. Dahl and Sterner (1991) also stated that the studies surveyed take different approaches on seasonality. They find that there is a striking difference between the results obtained when seasonality is taken into account, as opposed to annual measures. Dahl and Sterner (1991) conclude that seasonal data is inappropriate because the results are unpredictable and lack robustness, especially in the long run.

Cooper (2003) uses a lagged endogenous model to portray oil demand for 23 countries. Each country is modeled independently. U.S. own price elasticity is found to be -0.061 in the short run and -0.453 in the long run. Krichene (2002) simultaneously estimated two interdependent lagged endogenous world demand models: one where oil is the dependent variable and the other where natural gas is the dependent variable. In doing so, she is able to take advantage of the robustness and simplicity of the lagged endogenous model while accounting for certain interdependencies in the energy market. Krichene (2002) finds that the crude oil demand price elasticity is -0.005 in the most recent period estimated (1973-1999) which is almost perfectly inelastic.

Lin (2011) estimates oil supply and demand simultaneously and in the same manner and time period as Krichene, but decomposed prices and quantities into OPEC and non OPEC, yielding one of the most elastic measures for oil own-price elasticity of -0.095. A major departure from previous literature in estimating the simultaneous supply and demand equations for oil is the use of instrumental variables to deal with the identification problem of simultaneous estimation.

Karimu and Brannlund (2012) argue that energy demand models, like the above, too commonly rely on parametric models, such as the lagged endogenous model, and other log-linear models, which are less robust and more likely to be mis-specified than nonparametric models. They argue that most parametric models in energy demand are chosen for their computational convenience and ease of interpretation, not for their ability to explain the data or underlying behaviors. Their approach contrasts a log-linear demand estimate with a nonparametric kernel estimate using 1990 to 2006 data. They test and reject the log-linear specification and find that their less restrictive nonparametric model generates a more inelastic own price elasticity at -0.18 to -0.19, for energy as an aggregate.

Rothman and Ho Hong (1994) estimated oil demand utilizing three common structural demand models: translog, almost ideal, and logit. Their study tests the appropriateness of these different functional forms for energy demand beyond oil by including natural gas, electricity, and aggregates for liquid fuels, and food energy. They conclude the logit model better approximates demand for world energy and delivers more robust elasticity measures. Rothman and Ho Hong (1994), however, note the potential shortcoming of aggregating so many energy commodities and considering world demand instead of regional demands. They suggest that with less aggregation over commodities, the almost ideal model may do a better job explaining the data. Calculated energy demand price elasticities ranged from -0.6 to -1.0, which are substantially more elastic than most estimates from other studies.

Serletis and Shahmoradi (2008) examine the substitutability of energy commodities in the U.S. using the functional demand forms of the Fourier and Asymptotically Ideal Models (AIM). They include coal, natural gas, and crude oil in both equations as commodities demanded, but excluded electricity as separable in the representative agent's utility function from the other energy commodities. The functional forms utilized yield parameter estimates with global regularity. Their own price elasticity estimates for oil are -0.253 and -0.635 for the two models.

Differences between previous elasticity estimates partially stem from differences in structural versus reduced form models and their varying ability to explain the data. Additional differences can be attributed to the utilization of a demand system, which accounts for substitution between commodities.

2.3. Model

Estimating a linear, reduced form demand equation, as has been the predominant method in the literature, only partially controls for contract levels through estimation of a constant term. For a more precise treatment and interpretation of this contract quantity, the Generalized Almost Ideal (GAI) Demand System developed by Deaton and Muellbauer (1980) and Bollino (1987) provides the basis for estimation. GAI is specified as

$$w_i = \frac{c_i p_i}{\mu} + \left(1 - \frac{c' p}{\mu}\right)\left[\alpha_i + \gamma_i' \hat{p} + \beta_i \ln\left(\frac{(\mu - c' p)}{P}\right)\right] + \varepsilon_i \qquad (2.1)$$

where

$c_i =$ contract level of consumption of commodity i in billions of barrels (bbl) of oil equivalent,
$c =$ column vector of c_i,
$\mu =$ total expenditure on oil, natural gas, coal and electricity,
$p_i =$ real price for bbl of oil equivalent of commodity i,
$p =$ column vector of p_i,
$q_i =$ quantity of commodity i consumed in billions bbl/year of oil,
$w_i = \frac{p_i q_i}{\mu} =$ budget share for commodity i,
$\hat{p} =$ diagonal matrix of p_i
$\varepsilon_i =$ error term, and
$P = Exp\left[\sum_i w_i \ln p_i\right] =$ Stone's price index.

Traditionally, P is represented by the translog price index

$$\ln P = \alpha_0 + \sum_k \alpha_k \ln p_k + \frac{1}{2}\sum_k \sum_l \gamma_{kl} \ln p_k \ln p_l. \qquad (2.2)$$

For ease of calculation, Stone's price index is used. Using Stone's index instead of the translog price index leads to what is known as the Linear Approximate Generalized Almost Ideal (LA/GAI) Demand System. The approximation comes because Stone's price index is log linear as opposed to the highly non-linear translog price index. The contract level for each commodity is endogenous to the model. When the contract level is restricted to zero, the Generalized Almost Ideal Demand System (GAIDS) becomes the Almost Ideal Demand System (AIDS).

Adding up, homogeneity, and symmetry restrictions,

$(i)\sum_i \alpha_i = 1 \quad \sum_i \beta_i = 0 \quad \sum_i \gamma_{ij} = 0,$

$(ii)\sum_i \gamma_{ji} = 0$, and

$(iii)\gamma_{ij} = \gamma_{ji},$

are imposed on the model. Deaton and Muellbauer (1980) find that homogeneity is often rejected, which leads to the rejection of symmetry, given that symmetry is more restrictive than homogeneity. Nevertheless, it is common practice to impose all three sets of restrictions in accordance with economic theory. Further, the addition of the symmetry restriction may not significantly alter results after the imposition of homogeneity (Deaton, 1974). These restrictions are imposed because they are consistent with economic theory and the limited number of data points (yearly data for 1980-2009).

Using Stone's price index as an approximation affords opportunities other than simply making the demand system easier to estimate. An added benefit is that the price elasticity calculations for commodities i and j are simplified to

$$\varepsilon'_{ij} = \frac{\gamma_{ij}}{w_i} - \frac{\beta_i w_j}{w_i} - \delta_{ij}, \tag{2.3}$$

where δ is the Kroeneker Delta. Alston et al. (1994) demonstrate that wealth elasticities are

$$\varepsilon_i = 1 + \beta_i / w_i . \tag{2.4}$$

2.4. Data

Price and quantity demanded data are obtained from the Department of Energy (U.S. DOE, 2009) for oil, electricity, natural gas, and coal. This data contains annual price from 1980 to 2008 in different units for each commodity. All commodity prices are converted to price per barrel of oil equivalent ($/bbl). Similarly, quantity data is posted in various units depending upon the commodity. All quantity data is converted to billion bbl/yr equivalent (a measure of potential energy equal to that present in a barrel of oil). The conversion puts all contract level estimates and cross price elasticity estimates into the same units for straightforward interpretation. The original units for natural gas, coal, and electricity quantities are billions of cubic feet, thousands of short tons, and millions of kilowatt hours. Short ton of coal is converted to barrel of oil equivalent (boe) by multiplying by short ton to metric ton conversion (one short ton equals 0.907 metric tons) and then dividing by barrel of oil equivalent (one boe equals 0.2 metric tons of coal) (Ag Decision Maker, 2008). The final conversion factors for equating each commodity's quantity from its original form (units/time) to billions of boe are 1.72/10,000; 0.043/10,000; 0.0059/10,000 for natural gas, coal, and electricity. Because oil is already in boe, the conversion factor is only to change from thousands of bbls/day to billions bbls/year, which is 365/1,000,000.

2.5. Estimation and Results

In estimating this system, it is necessary to simultaneously estimate four equations (one demand equation for each commodity) because of cross parameterization. Specifically, the contract level of a commodity is endogenously estimated in its demand equation. Each demand equation also uses an aggregation of all contract levels for the supernumerary expenditure calculation $\frac{c'p}{\mu}$. To obtain an estimate of the supernumerary expenditure calculation that includes all contract levels, either recursive or simultaneous methods must be used. Taking this into account, a seemingly unrelated regression model is used as is the typical method for dealing with expenditure systems and other systems with supernumerary expenditure and contract levels.

Demand systems, specifically the almost ideal demand system, have been used in the past to estimate energy elasticities and other demand parameters (Rothman and Ho Hong, 1994). As such, there are similar works against which the estimates obtained here can be compared. To compare against a system that does not explicitly account for pre-commitments, the LA/GAI system is compared against the LA/AI.

The parameter estimates, including the endogenously estimated contract levels for each demand equation for LA/GAI, are in Table 2.1. With the exception of contract levels, the parameters themselves do not directly yield to economic interpretation. The elasticities derived from both models are displayed in Tables 2.2 and 2.3.

The cross price elasticity estimates in Table 2.2 suggest that most commodities in the system are compliments (negative cross price elasticity) instead of substitutes with the possible exceptions of oil and coal (GAI) and natural gas and coal (GAI). Natural gas and coal in particular are intuitively substitutes because both are used as feedstocks in the production of electricity. Neither of these elasticities, however, are significant at the 10% level. All other commodity pairs that are significant at the 10% level or less are compliments. In the LA/GAI system, eight of the sixteen estimated price elasticites are significant at the 10% or less level, whereas, in the LA/AI system 14 of 16 elasticites are significant. All own-price elasticites are significant.

Oil has a complimentary relationship with natural gas and electricity such that if oil prices increase by 1%, demand for natural gas and electricity fall by 0.22% and 0.26% in the LA/GAI system. Natural gas and electricity also have a significant relationship as compliments where a 1% increase in the price of natural gas reduced electricity demand by 0.30%.

The own price elasticities calculated from the two models are as expected. That is, own price elasticity measures for each commodity estimated using LA/AI are more inelastic than own price elasticity measures estimated using LA/GAI (at the average price and consumption levels). This result reinforces the intuition that if contract levels are a legitimate restriction on demand then own price elasticity estimates that do not account for contract levels will be more inelastic.

A similar explanation can be used to understand the wealth elasticities in Table 2.3. In the GAI specification, both oil and natural gas are luxuries with elasticities greater than one, whereas coal and electricity are necessities with elasticities smaller than one. In the AI specification, the estimated wealth elasticities for both oil and natural gas are smaller (less elastic) and the estimated wealth elasticities for both coal and electricity are larger (more elastic). Oil changes from a luxury to a necessary good, whereas electricity changes from a necessary to a luxury good. In both models, wealth elasticities were calculated at average price and consumption levels.

In Table 2.4 one can see that for oil and natural gas, contract levels account for 87% of average consumption compared to 74% and 68% for coal and electricity. Recall from earlier discussion that the closer we are to the contract level, without accounting for it through model specification, elasticity estimates will exhibit more inelasticity. The contract levels in Table 2.4 coincide with approximately 68-87 percent of average demand for energy commodities. It is also apparent from Table 2.4 that electricity, the energy commodity with the smallest average quantity demanded per year, has the lowest contract level (as a percentage of average demand).

It has yet to be demonstrated, however, that contract levels are indeed a legitimate restriction on demand for oil and energy. Because the AI model is nested within the GAI (AI specification falls out of GAI when contract levels are restricted to zero), a log likelihood ratio test can be used. Akaiki and Bayesian information criterion (AIC and BIC), which are other measures for comparison, are also considered. Because both the AIC and BIC are loss metrics, a smaller score represents a better fit. Both metrics are smaller for the GAI specification (Table 2.5).

The likelihood ratio test rejects the less restrictive model (LA/GAI) if twice the difference of the log-likelihood values exceeds a given value. For these models, with a difference of four degrees of freedom between specifications, GAI performs significantly better at the 1% level if the log-likelihood ratio statistic is greater than 18.47. The ratio between the two models is 73.11, implying that LA/GAI more accurately fits the data; forcing contract levels to zero is an unreasonable restriction.

It is informative to generate forecasts for commodity demands to compare the respective fits of each model to the data. Given the small number of observations in-sample forecasts are generated rather than the preferred out-of-sample forecasts. The actual quantity of each commodity demanded, as well as quantity demanded estimates using LA/GAI and LA/AI models from 1980 to 2008 are given in Figure 2.1. For each commodity, LA/GAI appears to follows the actual quantity demanded more closely than the LA/AI model. The better fit of LA/GAI is further demonstrated by having a consistently lower root mean squared errors compared to the root mean squared errors associated with the LA/AI model (Table 2.6). Inference from these tests and comparisons leads to the inference, that a model, which restricts contract levels to zero, imposes less realistic restrictions on the demand system than the model with contract levels.

Demand curves for each commodity under the LA/AI and LA/GAI specifications are illustrated in Figure 2.2. The demand curves for each commodity are calculated at the average observed price and quantity for all other commodities. For instance, when the demand curves for oil are generated, prices and quantities of natural gas, coal, and electricity are held constant at their average over the observed time period. The location of each pair of graphs in price and quantity space is less important than their slopes and relative positions to each other. Depending upon assumptions about the prices and quantities of the other commodities in the system, these two curves can move around in price and quantity space. Nonetheless, these graphs illustrate an important inference. Policies that might curtail the quantity demanded for oil (or any of the other energy commodities in the demand system) are less effective in a world where GAI and contract levels represent the "truth" concerning demand than in a LA/AI world.

2.6. Discussion

Energy and oil demand intuitively depend on contract levels. Estimation results and elasticities appear to confirm this intuition. A likelihood ratio test rejects the Almost Ideal in favor of the Generalized Almost Ideal. The Bayesian and Akaike's information criterion yield similar results; Generalized Almost Ideal specification is preferred over the Almost Ideal. Further, the coefficients representing contract levels are highly significant. Contract levels are over 68% of average quantity demanded. Because energy prices heavily influence macroeconomic variables, responses to price fluctuations are important in forecasting economic welfare of policy changes. Concerns of self-sufficiency and global warming, as well as, shifting political climates have brought with them ideologies which will affect energy prices. If policy makers wish to reduce carbon emission through cap and trade or other abatement policies, they need an accurate measure of demand responsiveness, which is captured through price elasticities. They must also be aware of the cross price effects of policies in one commodity market on other commodity markets.

Imposing abatement policies on one commodity market in a system as if the activities in that market are independent from the other(s) could larger than anticipated impacts on the industry in question or the economy as a whole. Further, the relationships between commodities could cause the policy to be rendered ineffective. Using the estimated cross price elasticities, a policy that results in an increase in the price of oil would reduce the quantity of oil demanded, but also reduce the demand for electricity and natural gas, and raise the demand for coal. If the goal of the policy is to reduce carbon emissions by increasing oil prices, for instance, coal consumption could increase as a result, yielding greater overall carbon emissions, ceteris parabis.

The cross price elasticity estimates indicate that in the short run nearly all energy commodities in the system are compliments with the exception of natural gas and coal, and oil and coal. The cross price elasticity estimates under LA/GAI, however, are not statistically different from zero for coal and oil. These results coupled with the wealth elasticities indicate that at least in the short run cross price elasticity measures are impacted more by wealth effects than substitution effects. The immediate implication is that a major part of the short run result from a policy or supply shock that increased oil price, for example, would be a decrease in both consumer wealth and consumption of other energy commodities in the system. Such a policy or shock would not only harm consumers, but other industries within the energy system.

Consider the world under the assumptions in the oil panel of Figure 2.2. If a demand system without contract levels is appropriate, a policy aimed at reducing oil consumption could accomplish a decrease in consumption from 7.6 billion bbls/year to 6.6 billion bbls/year by increasing the price of a barrel of oil by $3.39. If the demand system with contract levels is appropriate, the same reduction in quantity demanded would necessitate a price increase of $51.74/bbl. A policy aimed at any other commodity in the system would result in a similar outcome.

Several studies have estimated oil and energy own-price elasticities for the U.S. without the inclusion of contract levels. In Krichene (2002) the own-price elasticities from the short run error correction model and the long run estimation range from -0.02 to -0.13. Similarly, Cooper (2003), who estimates oil demand for 23 countries, estimates an own price elasticity for oil of -0.06 and -0.45 for the short and long run. The LA/AI model estimate elasticity is similar to the short run specifications estimated in these two papers with an elasticity of -0.11. All of these results exhibit extreme short run inelasticity. The LA/GAI, however, returns an own price elasticity of -0.3, which although still inelastic is far more elastic than previous short run calculations. Again, this is the anticipated result that a contract level model will find demand is more own price elastic when quantity demanded is above the contract level and less own price elastic when quantity demanded is at or near the contract level. Another consideration is that when the consumption of any energy commodity in the system is near its contract level, policy makers need to be aware that price responsiveness of demand is much smaller and price-centric abatement policies will have less of an impact on consumption and more of an impact on consumer wealth.

Rothman and Ho Hong (1994) also used an almost idea model to explain energy demand. They found energy elasticities near -1 using both logit and almost idea models. Though they conclude that the logit model is superior to the almost idea specification when applied to energy, they suggest that further delineation of "energy" into specific components or commodities could improve estimating power and efficiency. Serletis and Shahmoradi (2008) estimated two structural demand systems, Fourier and Asymptotically Ideal, with the same energy commodities considered here with the exception of electricity. The own price elasticity estimates for oil and natural gas bounded the LA/AI estimates with the LA/AI estimates being slightly more elastic than the Fourier estimation, but considerably less elastic than the Asymptotically Ideal Model estimates.

Contract levels, themselves, are also important. Implications to policy and government involvement in oil and gasoline markets are readily apparent. Because oil and energy commodities are matters of national and economic security, the government's interest in keeping supply available is obvious. By having ready estimates for contract levels, in the case of oil for instance, the government can establish a cushion of economic viability in terms of how much oil we need at minimum to keep the economy running. Such an estimate has obvious implications for the strategic petroleum reserve and calculating its longevity of economic support if tapped.

Specifically, the U.S. petroleum reserve contains more than 0.7 billion bbls of oil. In 2008, the U.S. consumed over 2.1 billion bbls of oil imported from OPEC. The average consumption for the U.S., from 1980 to 2008, was 6.5 billion bbls, with a contract level of 5.7 billion bbls. If OPEC were to embargo the U.S., the U.S. would still be supplied with 4.4 billion bbls (6.5 - 2.1 = 4.4). To meet the contract level, there would have to be another 1.3 billion bbls (4.4 + 1.3 = 5.7) generated from domestic and other foreign sources. In this circumstance, the strategic petroleum reserve would provide the necessary support for only (0.7/1.3) x 365 = 196 days, or about 6.5 months.

CHAPTER III

MODELING WORLD CRUDE OIL SUPPLY BY RESERVOIR PORTFOLIO

Textbook industry level supply models assume each firm has a unique cost function attributable to private knowledge, capital structure, and size. These individual supply functions are then aggregated to obtain the industry level supply curve. This assumption of unique cost curves at the firm level may not necessarily be true for the oil production industry. The oil industry is oligopolistic with the major suppliers often cooperating on individual production projects (Hill and Hellriegel, 1994). In the more industrialized oil producing countries, there are small-scale fringe producers that take over wells that have become less profitable relative to other alternatives larger producers face. These fringe producers do not change the cost structure of the well, but often take over towards the end of the well's productive life. Each major producer has a unique knowledge set that may cause minor stratifications in production costs throughout the industry, but the main cost differences in production are not between producers but between production reservoirs (Bradley and Wood, 1994).

A world oil supply curve is developed based upon regional oil production costs and quantities. Reservoir production and lifecycle costs are modeled as a function of reservoir characteristics. The ability to explain production costs as a function of reservoir characteristics indicates that production costs are innate to regions of the globe. If this is the case, the cost of supplying oil is determined more by the reservoir itself, and to a much lesser extent the variations in management techniques of the major producers.

The easier, cheaper oil to produce will continue to be easier and cheaper regardless of changes in production technology or changes in management. Variations in production technology in particular may affect different types of reservoirs differently. That is, a new technology may be developed that causes heavier more viscous crude oil to flow more easily, thereby greatly reducing costs of production from wells and reservoirs containing viscous oil. Even if this technology only changes the costs for heavy oils and does nothing for the cost structure of light oils, this technological advancement will most likely not make the more viscous oil suddenly cheaper to produce than less viscous oil.

The dependency of production costs on reservoir characteristics, therefore, implies that the resulting world oil supply curve and the current ordering of producing wells and countries along the supply curve is ordinal. That is, changes in production technology may reduce the cost of producing oil and even certain types of oil or reservoirs more than others, but the ordering of wells and regions from lowest cost of production to highest cost of production should remain essentially the same. This is important because it implies that although intensity of production may cause the scale of the supply curve to vary, a region's position along the supply curve is fixed.

Numerous policy initiatives are directed toward reducing world oil consumption. World and country specific policies range from pollution and associated climate change initiatives to country specific policies such as U.S. energy independence. No matter what the driver, a reduction in world oil demand would cause world oil price to fall. As world oil prices fall, oil reservoirs with higher relative costs may shut down production. If production from a relatively high cost reservoir does not shut down, new production activities on that reservoir may cease, causing production to decrease gradually from the reservoir as the established wells reach the end of their lifecycle. Higher cost reservoirs will contribute less to world oil supply with a reduction in world demand and world price. When production from a reservoir becomes infeasible at the prevailing price, the region or country loses revenue from the oil production.

Even if a producing country continues to produce the same quantity of oil after a fall in oil prices, the revenues they earn per barrel are smaller, thereby lowering per capita GDP, which is highly correlated with every major index of political stability (Marshall, 2008). If policies are successful at reducing demand, a potential unintended consequence is that oil producing countries, which are currently politically stable, may move toward instability, and politically unstable countries may become even more unstable as oil revenues and per capita GDP decline. Such effects need to be considered.

3.1 Objective

The objective of this chapter is to examine the effect on the U.S. and world oil suppliers of policies that are directed towards reducing world oil demand. To achieve this objective, the cost structure of world oil supply as a function of regional geology, namely reservoir characteristics, is modeled. This reservoir specific, world oil supply curve is used in three scenarios where world oil demand shifts is reduced by 2.5%, 5%, and 10%. Potential changes in the oil producing regions that result from each of these scenarios are discussed. Specific questions considered are: 1) how downward shifts in world oil demand, regardless of the source, will affect world oil price and oil producing regions; and 2) how changes in U.S. and world oil demand affect U.S. dependence on foreign oil.

3.2 Literature Review

As expected, there is an enormous volume of literature dealing with oil including literature that uses the word “supply.” Much of this literature, however, mistakenly uses the word supply to mean quantity consumed in a given year and not a schedule of prices and quantity supplied. Literature along these lines has been directed towards the production of oil and forecasts future production. Hotelling (1931), for example, argues that price paths for any exhaustible natural resource would follow the interest rate, as would supply. His theory poses some weaknesses, for instance, it cannot explain backwardation in the oil futures market. Though a good lens to make general inferences about the oil market, Rehrl and Friedrich (2006) argue that it does not explain real world observations. According to Adelman (1993), Hotelling’s theory does not describe oil production because it is based on a number of false assumptions including the fixed quantity of the asset, the perfect storability of the asset in-situ, and the sole proprietorship over the asset allowing preservation to a later date. In reality, oil production more closely resembles the tragedy of the commons, where multiple firms produce from the same reservoir and any oil a firm leaves in the ground can be extracted by others.

Sinn (1984) concludes that with costly storage (in-situ), there is an incentive to overproduce. Oil storage in situ is costly and as Adelman (1993 p. 5) notes, “A given reserve yields a decreasing flow. If nothing were done, in time production would cease.”

Rehrl and Friedrich (2006) suggest that the “better” model for oil production is a Hubbert curve, which tracks production by past production (exploration) and technological prowess (total recoverable) using a logistic model. The importance of this line of literature is undeniable to forecast optimal use of a limited resource. This line, however, does not address shorter-term supply curves. Fattouh (2007 p. 7) states “despite its main contributions, many economists consider that the literature on resource exhaustibility does not provide any insight into the oil price issue.”

Surprisingly, of this enormous volume of literature relatively few studies have been published with the express propose of estimating structural oil supply curves; curves in which the quantity supplied is a function of price and other exogenous variables. There is little doubt that a variety of supply and demand models for oil and gas exist, but the majority of these likely exist for the internal use of private industries that stand to benefit from such models (e.g., international oil and gas companies).

Although limited, some academic and publicly available research has been conducted in modeling world oil supply. Kennedy (1974) estimated a supply and demand model for world crude and other refined products. Refinery costs for crude and specified derived commodities were utilized in a linear programming model to determine equilibrium outputs. He found that competitive forces within OPEC would preclude significant future price spikes for oil. Wood et al. (2004) forecast supply quantities based upon current and past technologically recoverable barrels without explicit consideration of costs. In each scenario they forecast, world oil production will peak sometime in the 21^{st} century.

Both Considine (2006) and Alhajji and Huettner (2000) model supply using separate supply functions for OPEC and non-OPEC countries. Their cost data comes from the Department of Energy where Alhajji and Huettner (2000) assume the U.S. is the highest marginal cost supplier for the non-OPEC countries. Supply cost estimates for OPEC countries (specifically Saudi Arabia) are estimated as a function of security costs and an arbitrarily assigned production cost of $0.50/bbl in 1970 that increases at a 3% rate annually. Considine (2006) took a different approach by estimating a system of supply and demand equations using aggregate equilibrium data, but assumed the same cost function for OPEC member countries as Alhajji and Huettner (2000). To the author's knowledge, no academic studies have been conducted that estimate a world supply curve, using reservoir and well specific production and cost data.

Concerning strategic production and market structure, there is a breadth of literature with conflicting findings. These findings taken in aggregate provide some justification for treating OPEC countries similarly to any other oil producing/exporting country in a model. For instance, Gately (1984) surveys a decade's worth of research on market structure and cartel influence. Some studies have concluded that there is a first mover or cartel advantage to some suppliers (OPEC) while others conclude that the oil supply market is competitive (no signs of monopolistic control over output and prices). Gately (1984) concludes that OPEC exhibits some degree of monopolistic control over quantities, but that despite a significant amount of attention in the literature, oil supply and market structure continue to be overshadowed by many unresolved issues. Among the disagreements are the cost and capacity of alternatives and the geological resource base.

Also in contention is OPEC's ability to function as a cartel for extended periods. Most evidence points to the contrary. Adelman (1993) argues that it is in the best interest of OPEC member countries to maintain excess capacity whenever possible. Further, Tang and Hammoudeh (2002) concluded that OPEC actively manipulated production when oil prices diverged from a $15-$25 price band. Prices have been well above the $25/bbl mark every year since the study was published, while OPEC production has had no explicit upward trend. The implication is that OPEC either is producing near capacity and unable to increase production sufficiently to lower the price, or has changed its target price band to a much higher bracket.

An individual well or reservoir's contribution to supply not only depends upon its cost structure, but also on strategic or politically motivated depletion paths. It, therefore, is important to understand which explanatory variables define the cost equation for oil and their magnitude of impact (parameterization). Further, other factors that may affect production, for instance the fact that oil is an exhaustible resource must also be considered. Oil's exhaustibility as a resource has been discredited as a major factor contributing to world price, but there is no doubt that it becomes a tangible constraint at the well or reservoir level.

Because different technologies are utilized in different oil reservoir types (Directory 2010), it is possible to model production by reservoir types or characteristics. Wiggins and Libecap (1987) assert that oil production costs are an increasing function of well maturity. It is reasonable to assume a supply structure where firms' cost and production considerations are heavily influenced by the types of reservoirs they hold in their production portfolio (Energy Information Administration (EIA), 2011). Some firms may have cost of production advantages over others, but this would stem from their portfolio, which is less technologically demanding. Though managed by firms or governments, wells may then behave as individual price takers.

Unconventional oil reserves and production also play a role in world oil supply; a role which is only expected to grow in the future (Mohr and Evans, 2010). Mohr and Evans (2010) model current and future unconventional production. They find that even in the most optimistic scenario, unconventional oil only partially mitigates the peaking of the conventional oil supply. Further, current unconventional production techniques require vast water resources (Mohr and Evans, 2010). Unconventional oil is not considered in this study because unconventional oil only represents a marginal contribution to current supply, it is on the more expensive side of the supply curve, and virtually no data is available.

3.3 Supply Curve Market Structure

3.3.1 Market and Cost Structures

As noted by Beattie and Taylor (1993, p. 164), "The supply function of a firm that sells in a perfectly competitive product market gives the quantity that it will produce as a function of product price." In a perfectly competitive market, a firm sets marginal revenue (MR) equal to marginal costs (MC), but price (P) just happens to be equal to MR, that is MR = MC = P. Under perfect competition, a supply curve exists and it is the marginal cost curve. Several theoretical and real world issues can result in the condition of P = MC not holding, creating a wedge between the MC curve and the supply curve. Several such issues are imperfect competition, dynamics, and costs associated with changes in production. These issues, which may make the competitive theory of price equaling marginal cost in developing a supply curve suspect, are briefly addressed here with respect to the world oil market.

With imperfect competition, such as monopoly, P = MC is not the case. A firm still produces a quantity that equates MR and MC, but MR is no longer equal to the price. These firms face a downward sloping demand curve where the marginal revenue decreases with production or output. In imperfect competition, the supply curve is not the marginal cost curve. Ferguson (1966 pp. 236-238) states a supply curve can only be developed under different demand scenarios. The type of competition characterizing the world oil market will determine how the supply curve is developed.

At least four general theories of market structure exist: cartel or monopoly theory, dominant firm with a fringe (and its variations), non-profit maximizing model (target revenue theory), and competitive model (Griffin 1985). The first three theories are associated with imperfect competition. As noted above, in these theories price will not equal marginal revenue. Regardless of the theory, a supply curve that represents the quantity the market will supply for each price may be developed under various assumptions such as differing demand as noted previously. The development and justification of a supply curve, therefore, hinges on one's assumption of the market structure of the world oil market. Unfortunately, one can find literature supporting any of the general theories or their variations as best explaining world oil supply market structure (Smith, 2002; Gately, 1984; Tang and Hammoudeh, 2002). Time frame, methodology, and data limitations partially determine which structure a study determines as "best" (Smith, 2002). Another complicating issue is market changes (demand and/or cost fluctuations) that would cause players in an imperfect world to change their output will also cause participants in a perfectly competition market to change output levels. Empirically, these effects are indistinguishable (Smith, 2002). The issue becomes, what is the correct market structure?

A second reason price may not equal marginal cost even under perfect competition is dynamics associated with the allocation of a fixed stock x_t of a resource that is storable and allows production in period t, q_t, to be deferred to later periods without compromising the stock. To illustrate why price may not equal marginal costs, consider the following simplified example. In this example, let the price at time t be p_t, r be the discount rate, and costs to the firm of extraction represented by $c(q_t,x_t)$ where q_t is quantity produced and x_t is the state variable representing the fixed stock of the resource at time t. Further assume the firm's wants to maximize the net present of the extraction of the resource over an infinite-horizon. Under these simplified conditions the firm's problem is maximize the net present value of the use of the resource

$$\max_{q_t} V\left(x_t, p_t\right) = p_t q_t - c\left(q_t, x_t\right) + \frac{1}{1+r} V\left(x_{t+1}, p_{t+1}\right). \tag{3.1}$$

The first order condition for maximization with respect to q_t is

$$p_t - \frac{\partial c\left(q_t, x_t\right)}{\partial q_t} + \frac{1}{1+r} \frac{\partial V\left(x_{t+1}, p_{t+1}\right)}{\partial x_{t+1}} \frac{\partial x_{t+1}}{\partial q_t} = 0. \tag{3.2}$$

Rearranging this condition gives $p_t = \frac{\partial c(q_t, x_t)}{\partial q_t} - \frac{1}{1+r}\frac{\partial V(x_{t+1}, p_{t+1})}{\partial x_{t+1}}\frac{\partial x_{t+1}}{\partial q_t}$. Notice, because of scarcity rents issue raised by Hoteling (1931) theory price does not equal marginal costs. Price equals marginal cost if and only if $\frac{1}{1+r}\frac{\partial V(x_{t+1}, p_{t+1})}{\partial x_{t+1}}\frac{\partial x_{t+1}}{\partial q_t} = 0$, otherwise $p_t > MC_t$ because $\frac{\partial x_{t+1}}{\partial q_t} < 0$. The magnitude of this wedge between price and marginal cost will help determine the extent of the deviation between the marginal cost curve and the supply curve.

Shut down or start-up costs associated with wells are another potential source of a wedge between marginal costs and price. If there are costs to shut down a well, for example, a well may continue producing even though the marginal costs are below price to avoid these shut down costs. Similarly, a well that is not currently producing even though price is above marginal costs may stay out of production because of the start-up costs. The magnitude of these costs will determine how large the wedge is between price and marginal costs.

3.3.2 Assumptions Made and Justification

To complete this study, a decision on the market structure must be made. This decision impacts how the supply curve is generated and interpretation. As noted above, the literature is not conclusive on which structure best explains the world oil market. Further, over 200 countries produce oil along with more than 200 international and national oil companies (IOCs and NOCs) (not including independents) in the world. In 2011, the top five producer countries were Saudi Arabia (11.15 million barrels/day), Russia (10.24), United States (10.14), China (4.3), and Iran (4.2), with world production at 87.33 million barrels per day. Amongst the twelve OPEC countries (which do not include Russia, U.S., and China) production was 35.12 million barrels/day or 40% of world production. The data used in this study are based on actual produced quantities and production costs in 2010, where the literature most consistently finds the oil market to be "better" represented by the competitive model. With the recent empirically competitive nature of the oil market in mind as a first approximation, this study assumes a competitive market (no market power) to develop the supply curve so that the marginal cost curve offers a reasonable approximation of the world supply curve. Next, it is assumed price will equal an approximation of marginal costs (true marginal costs cannot be obtained as discussed in the methodology section). Further, justifications of these assumptions are provided.

3.3.3 Competitive Structure

Further evidence to support the assumption of competitive structure is provided. Griffin (1985) finds evidence of OPEC being a cartel, but non-OPEC countries appear to be operating within a competitive model. Ramcaharran (2002) using data from 1973-1997 results support a competitive model for non-OPEC members and a target revenue model for OPEC. He concludes, however, that "OPEC's loss of market share and drop in the share of oil-based energy should signal adjustments in price and quantity based on a competitive world market for crude oil" (Ramcharran 2002, p. 97). Almoguera et al (2011) find for the years 1974-2004 that both cooperative and non-cooperative behavior within OPEC has occurred. They conclude Cournot competition in the face of a competitive fringe is the best characterization over the entire period. This market structure includes some features found in perfect competition, homogeneous product and firms do not cooperate, but firms have market power in that firm decisions affect price. Lin (2009) finds that there is evidence for OPEC collusion and a monopolistic structure to the world oil market from 1973-1981, but that perfect competition better explains demand in more recent history. Holz and Huppmann (2012) also conclude the observed 2008 and 2009 oil prices are close to the competitive benchmark prices.

Colgan (2012) states the obvious, that many scholars and policymakers believe OPEC acts as a cartel that influences the world oil market by restricting oil production; however, he argues this view is wrong. OPEC is economically dysfunctional and, instead of a powerful cartel effectively exercising monopolistic power, is better described as a political club that generates political benefits for its members. Cairns and Calfucura (2012, p. 579) similarly suggests that countries gain political clout by joining OPEC and that

> "… playing the game consistently well would require organization, multinational operation for tankers and refineries, partners for joint ventures. Once capacity is sunk, the players face capacity and geological constraints on their actions that can be overcome, if at all, only by other long-run actions. Is it worth it in terms of their objectives? They do not seem to play the game well. OPEC does not control the agenda in oil; it reacts to the market."

3.3.4 Dynamics and Scarcity Rent

There are a number of reasons why the possibility for dynamic allocation of resources fails to create a significant departure from the static perfectly competitive framework. Several reasons are provided. Similar to market structure, studies that refute or confirm the dynamic nature and scarcity rent can be found. But, as mentioned in the literature review, Hotelling's original theory has repeatedly failed empirical tests when applied to oil production, because of a number of assumptions that may not apply to the world oil industry including costless storage and a fixed stock. Adelman (1993) states "The Hotelling Rule and Hotelling Valuation Principle are thoroughly discredited. A valid theory was joined to a wrong premise, the fixed stock. It gave results contrary to fact." Heaney and Grundy (2011) find no evidence to support Hoteling's relationship between price net of extraction costs and the market value of crude oil.

Another potential reason why scarcity rent may not be important in the empirical studies is because oil is drawn from a common pool. The old open access adage of "use it or lose" may apply to oil reservoirs. Oil storage (in-situ) is costly because of equipment rental costs whether or not production occurs, competition with other firms on the same reservoir (including common property aspects), and geologically dictated optimal extraction paths and flow rates. Along these lines, Galanos (2012) applies the Hotelling Valuation Principle to data from six super major producers and finds they behave as though oil is worth nearly twice as much once extracted as it is in the ground as reserves. Welfrens (2009) finds only weak evidence to support Hoteling's rule in the world oil market.

3.3.5 Start-up and Shut Down Costs

Startup and shutdown costs may also drive a wedge between the supply curve and the marginal cost curve. If there are barriers to entry such as startup costs then market prices can remain above marginal costs without competitors entering the market. Even if small profits are being made, new entrants are dissuaded by the barrier to entry of startup costs. For oil production, especially new wells, startup costs clearly exist. In the best-case scenario, when the existence of producible oil underground is a certainty, the well still needs to be drilled before it can be produced. Producing wells also have the ability to temporarily cease and eventually resume production with associated costs. These costs have a tremendous range depending upon the type of well, location, and maturity. Temporary shutdown costs for mature wells onshore could equate to the permanent loss of the remaining oil in the field (Wells, 2012). Offshore costs associated with temporary shutdown include at a minimum the day rates to rent the rig that would sit idle. These rates range from $50k/day to well of $400k/day (Rigzone, 2013).For the supply curve in this paper, costs are normalized to average lifecycle cost per barrel. Because of data limitation reasons, firms are assumed to make market entry decisions based upon the average cost, such that startup and shutdown costs are evenly distributed (or incurred) incrementally per barrel (a further discussion of this issue is presented in the methodology section). This means that firms do consider startup and shutdown costs when making production decisions, but that they are not considered barriers to entry. Finally, each reservoir is not assumed to produce at full capacity, but is instead scaled so that the aggregate production from all reservoirs within a country coincides with actual production by that country in 2010.

3.3.6 Outcome of Assumptions

The potential error of these assumptions would be the supply curve developed under competition would be to the right of the supply curve associated with the other market structures or price not equaling marginal costs, indicating that for any price, the competitive model would supply a higher quantity of oil than the other structures. Again, this is one of several competing theories regarding the correct form of the supply curve for oil. After considering each theory, the applicability of their assumptions to oil production, and the literature's review and empirical comparisons, the simplifying assumptions that give rise to a marginal cost supply curve appear appropriate for the oil market.

3.4 Data

Necessary data are crude oil production costs, reservoir characteristics, and production volumes. Further, to map oil production to geopolitical regions, information on geological basins by regions is necessary. Reservoir characteristics used to estimate onshore costs are recoverable reserves, oil density, depth, pressure, elevation, and dimensions (length x width). For offshore costs, reservoir characteristics used are the same as onshore except that instead of elevation (which is invariant for offshore reservoirs) water depth is used.

The above data, however, are readily available, especially the cost data. To overcome this problem, a methodology similar to one that has successfully been used to estimate production functions in agriculture is used (Dillon et al., 1989; Mjelde et al., 1988; Boggess, 1984; Musser and Tew, 1984). This methodology consists of summarizing output from large complex biophysical models using regression or other analyses to obtain production functions (Mjelde et al. 1988). Instead of a biophysical simulation model, a physical / cost simulator, IHS Corporation's Que$tor cost estimation software, provides the necessary data. IHS (2012) notes "QUE$TOR™ is an industry-leading software tool for capital and operating cost-estimation. More than 500 oil and gas estimators and managers in 48 countries rely on this consistent, global platform for concept screening, concept optimization and cost control."

Que$tor is a proprietary software that references a large database with information on costs, reservoir characteristics, and production data for wells worldwide. This database is used within Que$tor to construct detailed estimates of production costs for an inputted hypothetical well based on the reservoir characteristics, production plan, and capital requirements specified by the user. For the purposes of this study, cost estimates are generated for every reservoir in Que$tor, both onshore and offshore. A total of 411 cost estimates (250 onshore and 161 offshore) are obtained for oil reservoirs around the world. A summary of the number of well estimates generated by country and region is contained in Table 3.1. If a reservoir spans multiple countries, lifetime cost and operating cost estimates are generated for each country.

When generating a well estimate in Que$tor, the software requires the user to specify whether onshore or offshore, region, country, and reservoir. After the reservoir has been specified the user can modify any of the default settings for the reservoir. Default input settings are used to generate consistent cost estimates, commensurate to an average well on the reservoir. Default settings in Que$tor are not always true averages for production costs from a reservoir, but averages of historical production costs from the reservoir. This means that most default well estimates will be less expensive than a true average because, historically, cheaper oil is produced first. The default, however, should still be a good approximation of current average production costs, although less accurate for future oil production from the reservoir.

For offshore wells, Que$tor assumes a fixed default setting of 120 km from the well to the onshore operations base. Further, Que$tor does not account for "local content" requirements in their cost estimations. "Local content" refers to the requirements of certain countries (namely Nigeria, Brazil, and Angola) that oil production must utilize local resources such as labor and equipment, which grants monopolistic powers to local suppliers and raises costs of production. Fortunately, "local content" is only a factor in a few nations, and is a contrived element of regional production costs that would likely disappear if world prices for oil began to fall and production in those regions started to approach the break-even point. Even with these issues in default settings, the constructed supply curve should represent current minimum costs of production for regional reservoirs as their costs near world price.

For every reservoir estimate, Que$tor provides details on operating costs, total costs, lifespan of the well, and quantity produced by year and aggregate. Que$tor also outputs lifecycle cost/barrel of oil equivalent (boe) and operating cost/boe. These two measures are calculated by dividing the total lifecycle cost or total operating cost of the well from the time of construction through decommission by the barrels of oil equivalent produced during the time frame. Neither of these measures adjusts for inflation or discount rate; they are nominal representations of the ratio of cost to production quantities.

Price and production levels from BP (2011) are used to calibrate the estimated supply curve to 2010 market clearing price and quantity. Per capita GDP and population by country are from the CIA's World Factbook (2012).

3.5 Model

To generate the supply curve, wells are ordered from the smallest lifetime cost per barrel of oil produced (total lifetime cost/total barrels produced) to the largest cost. The average annual barrels of oil the well is expected to produce are aggregated across wells up to the reservoir level to form the supply curve. Average annual production from a given well is considered that well's marginal contribution to supply. The average annual production from each well is believed to be a reasonable approximation because each reservoir has multiple wells operating at different stages along their lifetime production profiles. Some wells may be producing at, above, or below average, such that when aggregating to the reservoir level, assuming average production from each well is a reasonable approximation. When the price increases above the lifetime cost per barrel of a well, the average annual production of that well is added to the supply curve. If price is below the lifetime costs per barrel, that well does not contribute to supply. The supply curve is composed of individual well production and costs, not aggregated production or costs by country. Producing regions with multiple reservoirs, like the U.S., therefore, are represented by multiple wells along the supply curve.

The supply curve includes the marginal contribution of an average well from each world reservoir in Que$tor. Reservoirs support multiple wells; therefore, if production from a reservoir is cost-feasible, many wells produce from the reservoir. It is necessary to aggregate from a well to reservoir level production. To accomplish this aggregation without good information on the number of producing wells per reservoir, the costs and production for each reservoir are scaled to coincide with each country's reported production levels for 2010 (the most recent available world production data).

Scaling the supply curve is a two part process that involves first truncating the data set to remove all wells with average operating costs that are higher than the average price of oil in 2010 (BP, 2011). Average operating costs are used instead of average lifecycle costs to truncate the data because 2010 production and prices are a result of past prices and future price expectations. Wells, therefore, may have been placed into production before 2010 because they were profitable given past prices or expected future prices. In 2010, as long as operating costs are low enough they would remain in production even if the lifecycle cost exceeded the market price because the fixed startup costs had already been incurred.

Second, the total reported production from each country is divided by the total production from all well estimates within that country. The resulting quotient is the scaling factor by which each well's production is multiplied within that country. Each reservoir within a country then produces a different quantity of oil, even though each reservoir's production within a country is scaled by the same factor.

For instances where oil producing countries were reported in BP (2011), but no cost estimates for those countries were available in Que$tor, production costs were approximated by equating them to nearby regions/countries that shared the same oil reservoirs. For countries where a single reservoir provided the only source of oil and a nearby country had production cost estimates from the same reservoir, production costs for the unknown country were set equal to the costs of production from the shared reservoir, not the entire production profile of the neighboring country (this is the case for Qatar, Kuwait, and UAE, which produce all of their oil from the Iranian-Arabian Reservoir). In no particular order, the countries that are approximated in this way are Azerbaijan, Equatorial Guinea, Qatar, Kuwait, UAE, Syria, Chad, and Sudan.

Conversely, some countries had cost estimates in Que$tor, but did not have production listed in BP (2011). In these instances, countries are categorized into regions of production in BP (2011) such as Other Africa, Other South and Central America, Other Europe and Eurasia, etc. These categories record production quantities that were not attributed to individual countries. Scaling is performed for each of these countries in a similar manner to countries that are directly attributed production. The only difference in scaling for these countries is that all countries in a category are scaled by the same factor, instead of each country being scaled by its own unique factor. To reiterate, each reservoir and country produces a different quantity of oil with a different lifecycle and operating cost; their average production is simply scaled by the same factor if part of the same region (e.g., South and Central America).

The constructed aggregate supply curve represents a depiction of the total quantity produced by region and the costs that each country faces in generating its total quantity of production. In accordance with earlier discussion, this supply curve is ordinal and, therefore, a consistently appropriate model of reservoir and country supply, only if production costs are driven by innate reservoir characteristics. To demonstrate the effect of reservoir characteristics on production costs a system of regression equations are estimated where production costs are explained by reservoir characteristics. These equations could theoretically be used to estimate production costs for reservoirs and countries not available in Que$tor. Unfortunately, no complete data sets were found regarding reservoir characteristics in any of these countries to allow for estimation, which is likely the reason that they were not available in Que$tor. Nevertheless, these equations provide a framework to recover costs from any region once reservoir characteristics are known and help to substantiate the ordinal nature of the proposed supply curve.

For the equations that follow, a well is a single producing platform or drill rig on a reservoir. Firms face a cost function for each well in their portfolio. The cost function depends on reservoir characteristics, equipment used, and production characteristics. Reservoir characteristics are exogenous because they are intrinsic to a region and are not caused by cost or production decisions. Equipment choice and production volumes also depend upon reservoir characteristics. The costs of oil production at a well, therefore, should be largely explained by reservoir characteristics even though costs depend on other factors as well like equipment costs. The cost model for oil production is composed of the following arguments:

Lifetime Cost = f(Reservoir Characteristics, Production Characteristics, Equipment)

where

Production Characteristics = G(Reservoir Characteristics), and

Equipment Choice = H(Reservoir Characteristics),

This simplifies to lifetime costs for a well as represented by a reduced form function of reservoir characteristics alone:

Lifetime Cost = Q(Reservoir Characteristics) (3.3)

Similarly,

Operating Cost = L(Reservoir Characteristics) (3.4)

The above equations are estimated using seemingly unrelated regression (Zellner, 1962). Operating and lifetime costs are recoverable from reservoir characteristics alone, strengthening the premise of a supply curve constructed as the aggregate output of all cost-feasible individual wells (cost-feasible meaning that the market price of oil is higher than the lifetime cost per barrel).

3.6 Scenarios

Using the supply curve with 2010 market clearing price and quantity as the baseline, world demand is decreased by 2.5%, 5%, and 10% to create three scenarios of what might happen if world oil demand decreased in response to external factors. Further, two different allocations of the decrease in world demand are modeled. First, decreases in U.S. demand are the same proportion as the decrease in world demand. In essence, all countries' demand is decreased by the same percentage. Second, the entire world demand shift is attributed to a decrease in U.S. oil demand only.

In 2010, the U.S. accounted for approximately 25% of world oil demand (BP, 2011). If U.S. demand were to account for the entire shift in the demand curve, a 2.5% world demand shift would result from a 10% U.S. demand shift (10% x 25% = 2.5%), whereas the 10% world demand shift would result from a 40% U.S. demand shift (40% x 25% = 10%). It is assumed that either world oil demand is vertical, or that the shift in demand is great enough for these scenarios such that a shift of 5% generates an equilibrium quantity demanded that is 5% lower. These shifts have varying degrees of feasibility, but serve to demonstrate effects on world supply and regional political stability.

In addition to changes in U.S. energy independence, changes in per capita GDP resulting from both oil price changes and local production changes are presented as a rough indicator of political stability for a country or region. Per capita GDP is highly correlated with all major indices of political instability; therefore, a percentage reduction in per capita GDP is indicative of a reduction in political stability.

3.7 Results

3.7.1 Regression Model

Regression results depict the nature of the relationship between costs (both lifecycle and operating) and reservoir characteristics (Table 3.2). With adjusted R^2 of 0.98 for onshore and 0.80 for offshore, the vast majority of well production costs and lifecycle costs are attributed to the reservoirs themselves, not the producing entity (reservoir pressure and reserves are two of the most consistently significant contributors to cost). These results provide evidence that the world oil supply curve is ordinal with respect to each country's position along the curve, although it should be noted that regressions are based on maintained assumptions within Que$tor. Ordinality is necessary for any meaningful discussion of the reduction in each country's production from demand shifts, or impacts on specific countries resulting from each scenario of reduced demand.

3.7.2 Supply Curve

As previously discussed, the supply curve is developed by plotting observations of cost and scaled quantity produced from wells worldwide (Figure 3.1). By design, the supply curve itself is non-differentiable and only piecewise continuous because it is an aggregation of individual production points. The structure of the oil supply curve can be inferred by observing the curvature. The slope of the supply curve begins relatively flat, where small changes in price are accompanied by large changes in quantity supplied. Essentially, at lower quantities the supply curve is highly own-price elastic. High price elasticity indicates that world oil price is relatively stable when the world quantities demanded and supplied, are relatively low. Small changes in demand, however, would have a large impact on marginal producers who at any given time are near the breakeven price.

Beginning at approximately $50/bbl, the supply curve rapidly changes toward a vertical curve; indicating a move toward an increasingly price inelastic supply curve. Own-price elasticity tends towards perfectly inelastic when all technologically possible oil sources are placed into production. Volatile oil market prices are expected in this portion of the supply curve because small changes in demand would have little impact upon quantities supplied, but large impacts on price. Given the volatility of oil prices in the past decade or so and the fact that world oil prices have been above $50/bbl, provides some validity for the estimated supply curve.

Supply price elasticity for oil is further corroborated by Considine (2006). Their model, which also utilized a short run supply outlook with various scenarios imposed, found that the U.S. Strategic Petroleum Reserve (SPR) could effectively reduce prices by contributing to supply in the event of shocks. The extreme inelasticity of the right hand side of the supply curve demonstrates why one may expect this kind of result in today's oil market. A very small change in quantity has a large impact on price. To the left of the curve, which is much more price elastic, a release from the SPR would have less of an impact on price.

Oil production by country in 2010 is compared to oil production obtained from the estimated supply curve in Table 3.3. Total world oil production in 2010 of 30,464.36 million bbls is less than 5% more than the "steady" world oil production obtained from the derived supply curve at the 2010 price (29,099.46 million bbls). Of the 85 countries modeled, 69 or 81% have a difference in production of less than 20% with 60 or 71% having a difference of less than 5%. Of those countries with more than 1% of the total world production (25 countries that account for 88% of total world production), only Angola's production difference is larger than 3.7%. The reason Angola has such a large deviation between actual 2010 production and supply curve production is that although Angola's average operating cost/boe is relatively low at $37.63, it has relatively high lifetime cost/boe at $100.68. Therefore, with 2010 oil prices being greater than $73/bbl, production costs are met and any production activity in Angola from previous years would continue. Lifecycle costs, however, are above world price, causing production to fall and new investment to cease if world prices were to remain around $73/bbl. The drivers for its high lifecycle costs likely stem from equipment requirements for extracting oil at more than twice the water depth of the average offshore reservoir and the relatively few recoverable barrels (Angola's reserves are less than 10% of the average reservoir).

3.7.2.1 Changes in World Oil Production as Demand Decreases

As expected, given the different costs structures of the reservoirs, decreases in world oil demand will affect countries differently (Table 3.3). At one extreme, Saudi Arabian production is unaffected by a decrease in demand; production does not decrease even with a 10% decrease in world oil demand. The United Kingdom, on the other hand, experiences a 12% decrease in production with a 2.5% decrease in demand and a 45% decrease in production if demand decreases by 10%.

Many of the marginal producing countries experience a 100% decrease in production. At the 2010 price of $73/bbl, Azerbaijan, Uzbekistan, Spain, Barbados, Tajikistan, Czech Republic, and Poland will eventually stop investing and cease production. A 2.5% reduction in demand leads to the countries of Angola, Afghanistan, Philippines, Latvia, and Mongolia ceasing production activities. When demand decreases by 5%, additional countries of Demark, Japan, Taiwan, Cambodia, Myanmar, Bolivia, and Guatemala cease production. Finally, with a 10% decrease Italy, Tunisia, South Korea, Chile, Ireland, France, Netherlands, and Croatia also cease production.

3.7.2.2. Impact on Gross Domestic Product (GDP) and Stability

Aside from the challenge and feasibility of reducing oil demand, there is the question of impact on other oil producing countries from a demand shift. The slope of the supply curve has an impact on country revenues regardless of where along the curve they fall. There are two factors affecting a country's revenue from oil when world demand shifts. The most obvious factor relates to the position of that country's wells/reservoirs along the supply curve. If demand shifts to the left and intersects the supply curve at a price lower than the lifetime cost per barrel for one or more wells within a country, production will cease from those wells. All revenue from those wells, therefore, will be lost.

A downward shift in the world demand curve also puts downward pressure on the price, especially in the highly inelastic portion to the right of the supply curve. This is the second factor that reduces a country's oil revenues, the loss of revenue from still producing wells due to the lower price of oil resulting from a downward shift in demand. The potential change in production for every producing country under each scenario of a downward demand shift and the market-clearing price that results from the shift is presented in Table 3.3.

Displayed in Table 3.4 is the change in per capita GDP by country that would result from each demand shift. These estimates assume a change in GDP from only lost oil revenues ceteris parabis. Countries with the largest decrease in per capita GDP are also the countries whose oil revenues account for the majority of their GDP. Afghanistan is at the top of the list and would experience nearly an 84% reduction in per capita GDP from only a 10% decrease in world oil demand. This would lower Afghanistan's per capita GDP from an already meager $1,000 USD to roughly $162 USD, making a politically unstable country even more unstable.

Oil revenue has the potential to affect political instability because it affects per capita GDP, which is highly correlated with every measure of political instability (Marshall, 2008). To roughly examine how stability may be impacted on average, ViewsWire (2007) instability index was regressed as a function of the per capita GDP in 2007 for all 165 countries listed in ViewsWire (2007). The log of the instability index is regressed on the log of per capita GDP yields a coefficient of -0.14, which is significant at the 1% level. A simple interpretation is a 1% decrease in per capita GDP increases the instability index (more unstable) by 0.14%.

Politically unstable oil exporting countries pose a threat to the industrialized world through supply outages (tactical or otherwise). The other side of the coin is that if politically unstable countries produce the majority of the world's oil, they will be amongst the most affected by demand shifts. Even if the oil that such countries produce is the lowest cost, they will suffer revenue losses from the lower market price of oil that accompanies a demand shift.

3.7.2.3. U.S. Demand Changes and Oil Independence

The above results are independent of the source of the reduction in world demand for oil. Here, two scenarios of the source are examined in relationship to U.S. production and consumption. The first scenario assumes the shift in world oil demand is shared equally among all consuming nations; therefore, the U.S. demand shift is proportional to the total demand shift. The second scenario assumes the entire shift in world oil demand is caused only by a change in U.S. oil demand.

In Table 3.5, the percentage change in the ratio of U.S. production to total consumption is displayed for every demand shift scenario (energy independence measure). When the demand shift is proportional, a 2.5% reduction in demand improves U.S. energy independence by 2.56%; whereas, a 5% reduction in demand does less to improve U.S. energy independence with improvement of only 1.46%. A 10% reduction in demand leads to a 3.37% improvement in energy independent. This result is attributable to the dispersion of U.S. reservoirs along the supply curve. The U.S. produced over 2.7 billion bbls of oil in 2010; the majority of those barrels coming from relatively low cost reservoirs in Alaska. Yet, some of the U.S. oil reservoirs are more costly, including reservoirs in California and the Gulf of Mexico, which begin to drop out of production when world demand decreases by 5% or 10%, regardless of the source of the decrease.

When U.S. demand reductions account for the entire shift (All U.S. in Table 3.5), as expected the change in energy independence is greater than the proportional scenario. A 2.5% shift in world demand coming only from the U.S. would mean a 10% shift in U.S. demand, because U.S. demand is approximately 25% of world demand (10% x 25% = 2.5%). Under this scenario, the percentage change in energy independence is 11%. The more drastic change of a 10% world reduction caused by a 40% decrease in U.S demand leads to a 55% increase in energy independence. Inferences from Table 3.5 question the soundness of the energy independence arguments. In the absence of game changing technologies, achieving self-sufficiency from demand side management is not meaningful.

Yet, there is still another side to the argument for energy independence that must also be considered. Aside from the challenge and feasibility of reducing U.S. oil demand; there is the previously discussed impact of the reduction on other oil producing countries. One potential cost of the U.S. increasing its oil self-sufficiency is the potential increased political destabilization in some producing countries. Trade-offs between improving the U.S. national security position through increased self-sufficiency and political destabilization appear to be real, although rarely discussed when the issue of self-sufficiency is discussed in the political and media arenas.

3.8 Discussion

The near verticality of the right hand side of the supply curve is indicative of the infeasibility and potential ramifications of the oil independence argument. Highly inelastic supply will cause demand shifts to have a much larger effect on price than on quantity. It, therefore, would take a large demand shift to bring about a relatively small change in quantity supplied. For the U.S. to become more energy independent, a higher percentage of its demand must be met by domestic production.

Improving U.S. oil independence requires consuming not only less oil from foreign producing countries, but less in proportion to the amount produced domestically. Demand reduction alone, therefore, does not guarantee improved independence because it does not necessarily reduce the ratio of imported oil. To improve oil independence the ratio of domestic production to domestic consumption must increase. Oil independence is only achieved through a demand shift if the fall in domestic consumption is not matched by a proportional fall in domestic production. That is, the domestic sources must continue producing at pre-shift levels, or mitigate production to a lesser extent than foreign producers mitigate.

As the results show, the only way to improve U.S. energy independence by more than 3%-4% is for a major reduction in U.S. demand. There are only two foreseeable ways that such a major demand shift could occur; either a technological advance or government energy policy. A technological advance capable of greatly reducing oil demand, however, would also be adopted by much of the rest of the world, drastically lowering world demand. This would not only hurt U.S. revenue, but also cripple the economies of many of the world's politically unstable oil producing and exporting countries in the process.

This type of result is expected, but an unintended consequence of the policy. In an effort to depend less upon politically unstable countries for oil production, the U.S. may, ironically, bring about an increase in the instability of countries it imports oil from, to a disproportionately large degree than it lessens its dependence upon those countries. Two factors are at play and inextricably linked: the percentage of domestic oil demand satisfied by foreign imports, and the political stability of the countries from which oil is imported. These factors are inversely related such that reducing U.S. demand and the quantity of oil purchased from abroad, increases foreign instability. Further, U.S. demand reduction lowers U.S. oil revenues and U.S. GDP. Therefore, unless considerable preference is given to reduction of oil imported from abroad as opposed to stability of oil supplying nations and impact on U.S. GDP, any policy curtailing U.S. oil demand will have a net negative impact on the U.S.

Beyond the plight of U.S. energy independence, the results demonstrate that even small changes to world oil demand, regardless of the source, have impacts all over the world. Reductions in demand for oil have been sought worldwide as beneficial to the environment and domestic self-sufficiency. In light of the extreme inelasticity of portions of the supply curve, the variance in oil production as a percentage of GDP, and variance in regional reservoir costs, many producing countries are susceptible to major economic impacts from oil policies of others. Few oil producing countries are insulated from these impacts, and even those that are, like the U.S., are still adversely affected.

An implication is that all oil policies, regardless of the intended benefit, must be weighed against these lesser-considered ramifications. No country's protectionist or reductionist policies for oil affect only that country. Producing countries all benefit from global emissions reductions, but are also damaged, and to differing degrees, by demand reductions.

CHAPTER IV

INTERSECTION OF U.S. SUPPLY AND DEMAND CURVES

World oil prices and market clearing quantities arise from the intersection of the world excess supply and demand curves for oil. Both curves represent an aggregation of all countries participating in the world market. Countries such as the U.S. with excess demand import oil at the world price. If the U.S. were to achieve energy independence in oil (zero imports), the U.S. supply and demand curves would determine the U.S. market price if this price is either below the world price or regulations ban all imports. Not only is the intersection important, but the slopes of the curves at the intersection, because they indicate the potential effects of shifts in demand and/or supply.

Strategic imports such as oil have an economic cost associated with them, which is not reflected in the market price. This cost is associated with national security, which has the characteristics of being a public good. Public goods are goods whose consumption is indivisible. Indivisible consumption is consumption that is nonrival and nonexcludable. This additional cost of national security is referred to as a vulnerability premium. As illustrated in the theory section, this vulnerability premium needs to be added to the world price to determine if the U.S. should be self-sufficient or energy independent (Tietenberg and Lewis, 2008). If the world price plus the vulnerability premium is more than the equilibrium price of the U.S. without imports then economic theory suggests the U.S. should be self-sufficient. If the premium plus world price is less than the U.S. autarky price, the U.S. is better off importing oil and not being self-sufficient. Both the vulnerability premium and U.S. equilibrium price without imports determine whether the U.S. should be self-sufficient.

4.1 Objective

Providing information on the U.S. equilibrium price to help determine if the U.S. should be self-sufficient is the objective of this chapter. Once the U.S. equilibrium price is determined, economic inferences on the size of the vulnerability premium necessary for the U.S. to self-sufficient are presented. To accomplish this objective, the U.S. demand curve that is estimated in Chapter II is overlaid with a U.S. supply curve from Chapter III.

4.2 Simple Economic Theory of the Oil Vulnerability Premium

Consider the U.S. supply and demand curves for oil as represented by the domestic supply and domestic demand curves in Figure 4.1. In a state of autarky, the U.S. would achieve equilibrium at the intersection of these two curves, with corresponding price and quantity of P_3 and Q_3. When the U.S. is involved in international trade for oil, the world oil supply curve is introduced. For simplicity, assume the world price is fixed at P_0. At this price, the U.S. quantity supplied would be Q_0 and quantity demanded Q_2. The difference between Q_2 and Q_0 is the amount of oil imported.

Allowing for trade lowers the price and improves domestic consumer surplus compared to the autarky equilibrium. As previously discussed, trade also exposes the U.S. to national security concerns. This exposure can be seen by considering an embargo. If the U.S. were engaging in free trade for oil at a price of P_0, an embargo would cause an immediate shift in domestic oil consumption to a short-run price that is much higher (P_2) and a quantity that is much lower (Q_0) than the autarky equilibrium. This is the risk the U.S. becomes exposed to when engaged in free trade; a cost to national security that is not reflected in the market price (P_0).

If national security costs are considered, a vulnerability premium would be added to the world price giving an effective market price of P_1. At a price of P_1, the U.S. consumes less oil and produces more domestically than would be the case under free trade. Consumer surplus is higher than it would be under autarky and the U.S. is better protected from an embargo than with free trade. In this case, the impact of the embargo is much less as the short-run price goes to P_4 and quantity consumed is Q_1. For the case depicted in figure 4.1, self-sufficiency in oil (the autarky equilibrium) is not merited because even with the vulnerability premium the price of oil plus the premium is less than the equilibrium price under autarky. This is most likely the case because of the small probability of a complete embargo. Only in the case of the premium plus world price being larger than the U.S. autarky equilibrium price is self-sufficiency warranted.

Several studies have examined the vulnerability premium associated with U.S. oil imports, how to mitigate national security concerns associated with free trade, and whether the U.S. should strive towards self-sufficiency in oil. Broadman (1986) explains the interrelated components of the social costs (which he terms the demand component and the disruption component) that need to be considered when empirically estimating the U.S. oil vulnerability premium. He surveys 18 studies that attempt to estimate this premium. Premiums from these 18 studies range from \$2 to \$124 per bbl with an average of \$27. The wide range of estimates is attributed to the large number of assumptions that are involved in achieving such an estimate, and to common weaknesses in every approach. The biggest weakness in each approach stems from poor treatment of supply and demand elasticities. Broadman (1986) does not explicitly calculate a vulnerability premium, but suggests the best policy tool for reducing U.S. vulnerability from foreign oil imports is to place a tariff on foreign oil to increase U.S. supplies and to add to the Strategic Petroleum Reserve (SPR) to subsidize domestic supply in the event of foreign disruptions.

More recent studies exist, but suffer from similar assumptions and inadequate treatment of supply and demand as those surveyed by Broadman (1986). Brown and Huntington (2010), for instance make a number of assumptions about future price points, and foreign oil disruption risks, while utilizing in their calculations average demand and supply elasticities from the literature. They calculate a vulnerability premium of $4.89/bbl. Leiby (2007) constructs an equation to calculate the U.S. oil vulnerability premium, but does not evaluate this equation to generate a numerical result. A common, yet significant flaw in all of these studies is the assumption that the supply curve is continuous at the average point elasticity. That is, they assume not only that point elasticities approximate elasticities at other points along the supply curve, but that the domestic quantity supplied is increasing with price throughout the ranges they analyze.

4.3 U.S. Oil Supply and Demand

The U.S. demand curve is generated using the LA/GAI estimates from Chapter II by setting the prices and quantities of all other commodities in the demand system (natural gas, coal, and electricity) to their 2008 levels (the most recent data available for electricity prices and quantities used for the demand model). The supply curve for the U.S. is generated in a similar fashion to the world supply curve in Chapter III. As in Chapter III, all individual well estimates are aggregated and scaled to coincide with U.S. oil production in 2010 (BP, 2011). In 2010, U.S. oil production in was 2.7 billion bbls/yr, and the price for a barrel of oil was greater than $70/bbl. The highest estimated lifecycle cost per barrel for the U.S. in Que$tor was less than $70/bbl. All known and estimable U.S. oil resources, therefore, were in production and contributing to the U.S. supply curve in 2010 that cumulatively produced 2.7 billion bbls/yr. Both the supply and demand curves are plotted in Figure 4.2.

4.4 Discussion

It is immediately apparent in Figure 4.2 that there is no intersection between the U.S. supply and demand curves, and one can easily see why. At an oil price of $70/bbl or higher, the U.S. is producing oil from all the reservoirs whose cost and production profiles are estimable within Que$tor. Total production peaks at 2.7 billion bbls/yr, while the quantity of oil consumed by the U.S. is 6.8 billion bbls/yr. For the U.S. supply curve to intersect the U.S. demand curve, even at the contract quantity of 5.6 billion bbls/yr, the U.S. would have to more than double annual production.

The supply and demand curves are calculated for different years (the demand curve for 2008 and the supply curve for 2010). This does generate some incompatibility. This limitation, however, does not detract from the main result, but rather strengthens the inference. Oil supply has historically expanded in terms of recoverable quantities (BP, 2011), such that a 2010 supply curve should actually stretch farther to the right than a

2008 curve. This has historically proved true for the U.S. with 8.7% higher reserves in 2010 compared to 2008, even though prices were higher in 2008. The 2008 average world price was over $91/bbl, whereas, the 2010 price was a little over $73/bbl (McMahon, 2013).

The theory of oil vulnerability premiums implies that if the true social cost (world price plus vulnerability premium) is above the autarky equilibrium price then a country should be self-sufficient in oil. The U.S. domestic short run supply and demand curves, however, do not intersect to form an equilibrium price. The vulnerability premium, then, would have to be infinite to argue that it would be socially optimal for the U.S. to be self-sufficient in oil. Even the highest vulnerability premium reported in previous studies of $124/bbl, does not come close to approaching the infinite level required. Further, because the quantity of oil the U.S. supplies is limited not by price in the current market, but by physical and technological limitations, the tariffs which Broadman (1986) suggests will improve domestic production, will instead only transfer consumer surplus to domestic suppliers and the government.

CHAPTER V

DISCUSSION AND CONCLUSION

Oil is the most heavily consumed energy commodity in the U.S. and throughout the rest of the world. As a result, there has been a preponderance of literature in economics aimed at modeling the industry, demand, competition, and supply. On the supply side, the literature has explored deeply into optimal extraction paths for oil. Also, many studies have estimated future aggregate oil production using time series regression models.

On the demand side, many papers have utilized reduced form estimation techniques to estimate demand for oil and/or other commodities such as natural gas. These studies are wide ranging in terms of the number of commodities included and the localization of demand to a region. Fewer studies have used structural form equations, such as the Almost Ideal, to estimate demand for oil as a system of demands for energy commodities.

This dissertation adds to the above literature by addressing three issues. Demand for oil and energy commodities in the United States is estimated using structural demand models that incorporate contract or pre-commitment levels. Previous studies have not explicitly addressed contract levels and the changes their inclusion makes to elasticity estimates, which then impact the efficacy of policy. Second, a world oil supply curve is constructed that allows for comparison of regional costs and for insight into changes in world supply balances. Unintended outcomes of policies or technological advances that reduce oil demand are examined using this model. Finally, the U.S. supply and demand curves are compared to address the issue of the U.S. becoming "energy independent" in oil.

The demand model estimates a contract level for oil that is nearly three times larger than the U.S. domestic oil supply. This contract level would indicate that in the short run, there are no price adjustments that could move the U.S. market anywhere near self-sufficiency in oil. Moreover, cross price elasticities from the demand model suggest that attempts at oil price adjustments would also affect demand for natural gas, electricity, and coal.

The world oil supply model suggests that a small decrease in demand of approximately 2.5% can generate an equivalent percentage improvement in U.S. "energy independence" in oil. Such changes, however, have potential other costs including increased political instability in producing countries and lost U.S. revenue from oil production. Further, it appears the vulnerability premium associated with oil imports would have to be infinite for the justification of self-sufficiency in the U.S. oil market. In the absence of a major change in technology or preferences, it appears no reasonable demand side policies will culminate in the U.S. being self-sufficient in oil.

Other conclusions drawn from these models suggest that energy is a much more complicated and interconnected system than we often take it to be with wide ranging complications all over the world to any perturbation. To demonstrate these points, the elasticities from the demand model and implications from the supply model are combined, to make inference into the feasibility and net impact of shifts in oil demand.

Each barrel (42 gallons) of oil is capable of generating 44 gallons of gasoline. The reason 42 gallons of crude oil creates 44 gallons of gasoline is that during refining only 19.5 gallons from each barrel of crude goes towards the production of gasoline, but 24.5 gallons of other additives are introduced to create the final product (this is referred to as Refinery Processing Gain (EIA, 2012)). In 2010, the U.S. consumed 3,307 mbbls/yr of gasoline and 6,989 mbbls/yr of oil; creating an oil to gasoline consumption ratio of 2.11:1. Only about half of the demand for oil, therefore, is attributable to demand for gasoline. It is reasonable, then, to assume that a 2% reduction in gasoline demand would cause a 1% reduction in oil demand.

From Chapter III, the only scenario is which the improvement in U.S. energy independence (2.56%) is greater than the reduction in demand is the 2.5% reduction in oil consumption scenario. For this scenario to arise from a change in CAFÉ standards, gasoline demand would need to fall by twice that amount or roughly five percent. The change from targeting oil demand directly, to targeting oil demand through gasoline demand affects the efficacy of the policy. If oil demand is targeted directly, oil demand is reduced by less than the consequential improvement in energy independence. If oil demand is targeted through policies on gasoline demand, the gasoline demand reduction must be twice the consequential improvement in energy independence. From Table 3.3, a 2.5% drop in oil demand causes the equilibrium price of oil to fall by more than 30%. Cross price elasticities from Chapter II suggest that the demand for natural gas and electricity will increase by 6.6% and 18.6%, while demand for coal will fall by 2.4%. U.S. GDP would also fall by approximately 0.36% ($55.4 billion).

From an economic and environmental standpoint, the outcome from targeting gasoline demand could actually be considered a positive, which under this scenario, speaks to the potential of small improvements in energy independence being not only feasible, but also effective in a number of different ways including reducing pollution (EIA, 1998). With a 5% reduction in gasoline demand, energy independence would improve and consumption of less polluting commodities would be increased to take up the slack in demand, namely natural gas and electricity. Use of coal also decreases.

The conclusion is that small percentage decreases in oil demand can generate similar, or larger percentage improvements in “energy independence”. Also, the reduction in oil consumption is accompanied by a reduction in coal consumption as the two are compliments. If the true objective of “energy independence” in oil, therefore, is to improve the economic welfare of the U.S. and does not include ramifications to other oil producing countries, then small changes in gasoline or oil demand through policies or technological changes could be beneficial. Larger changes of 5%-10% are actually counterproductive in terms of energy independence and U.S. GDP, but may improve pollution because of less oil being consumed and also less coal. Therefore, small improvements in energy independence can be made through small reductions in oil demand. Large changes in energy independence do not appear to be feasibly achieved through technological change or policies that reduce oil or especially gasoline demand. When the ramifications estimated here are considered, no demand side reductions generate a clear net benefit for the U.S., unless the stability of foreign oil suppliers is immaterial. "The key lesson from all of this is that we need to broaden our horizons when thinking about oil policy. We are all in this tub together" (Nordhaus, 2009 p. 13).

5.1 Limitations and Recommendations for Future Research

U.S. oil demand is estimated in a demand system that considers three other energy commodities, coal, natural gas, and electricity. Data concerning other commodities in the energy system such as biofuels and nuclear power, is limited. Including these other commodities would make an interesting study of cross price elasticities between these additional commodities and the ones included here. The inclusion of new commodities would require additional years of observations as well. Additionally, estimating an oil and energy structural demand system with contract levels for the entire world could be informative. Modeling such a system, which includes widely traded commodities such as oil, and commodities with limited international trade, such as electricity, would prove challenging.

A world oil supply curve is generated using world oil production statistics and reservoir costs. This supply curve does not include national fiscal terms as contributing to costs. Fiscal terms in oil and gas refer to the nationalistic policies and tax structures that affect the cost of producing oil. Without the inclusion of fiscal terms, the supply curve reflects that actual intrinsic cost of producing oil from each reservoir. Fiscal terms are assumed to be non-binding as world prices approach a country's actual cost of production. That is, if prices fall and a country is faced with the choice between producing no oil or relaxing fiscal terms, it is assumed that countries will relax or eliminate their fiscal terms. The supply curve in this study, therefore, should represent the price points and quantities that consumers face. Fiscal terms, however, do affect the profitability of producers from reservoirs that are below the equilibrium price. A compelling further study would be to add the additional costs of fiscal terms to each reservoir and examine how these fiscal terms re-order the costs of reservoirs.

In this dissertation supply and demand were estimated separately using different techniques. Another approach that would provide an intriguing comparison is to estimate supply and demand together as a system.

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APPENDIX I

TABLES

Table 2.1 – Energy Commodity System Parameter Estimates Using LA/GAIDS and LA/AIDS.

Commodity	Parameter	Estimated Coefficient	Standard Error	Commodity	Parameter	Estimated Coefficient	Standard Error
			LA/GAIDS				
Oil	c_1	5.690	0.081	Natural Gas	c_2	3.657	0.133
	α_1***	0.283	0.047		α_2	-0.082	0.092
	β_1	0.017	0.020		β_2***	0.149	0.042
	γ_{11}***	0.118	0.013		γ_{21}	-0.017	0.013
	γ_{12}	-0.0171	0.013		γ_{22}	-0.001	0.033
	γ_{13}	-0.004	0.018		γ_{23}	0.020	0.033
	γ_{14}***	-0.097	0.016		γ_{24}	-0.002	0.025
Coal	c_3	3.274	0.0568	Electricity	c_4	1.440	0.018
	α_3***	0.557	0.083		α_4***	0.242	0.057
	β_3***	-0.159	0.050		β_4	-0.008	0.031
	γ_{31}	-0.004	0.018		γ_{41}***	-0.097	0.016
	γ_{32}	0.020	0.033		γ_{42}	-0.002	0.025
	γ_{33}	0.049	0.064		γ_{43}	-0.066	0.048
	γ_{34}	-0.066	0.048		γ_{44}***	0.165	0.042

Table 2.1 Continued

Commodity	Parameter	Estimated Coefficient	Standard Error	Commodity	Parameter	Estimated Coefficient	Standard Error
			LA/AIDS				
Oil	α_1***	0.421	0.067	Natural Gas	α_2	0.004	0.041
	β_1	-0.018	0.024		β_2***	0.092	0.014
	γ_{11}***	0.144	0.007		γ_{21}***	-0.033	0.005
	γ_{12}***	-0.033	0.005		γ_{22}***	0.096	0.008
	γ_{13}***	-0.029	0.011		γ_{23}**	-0.018	0.008
	γ_{14}***	-0.082	0.007		γ_{24}***	-0.046	0.010
Coal	α_3***	0.693	0.107	Electricity	α_4*	-0.118	0.067
	β_3***	-0.119	0.039		β_4**	0.045	0.023
	γ_{31}***	-0.029	0.011		γ_{41}***	-0.082	0.007
	γ_{32}**	-0.018	0.008		γ_{42}***	-0.046	0.010
	γ_{33}***	0.183	0.020		γ_{43}***	-0.136	0.013
	γ_{34}***	-0.136	0.013		γ_{44}***	0.264	0.016

*, **, and *** indicates that the estimated coefficient is statistically significant at the 10%, 5%, or 1% level.

Table 2.2 - Cross Price Elasticities for Both LA/GAI and LA/AI.

		Oil	Natural Gas	Coal	Electricity
Generalized	Oil	**-0.3041*** **	-0.1235	-0.0505	-0.6257***
		(0.095)	(0.091)	(0.090)	(0.098)
	Natural Gas	-0.2218**	**-1.1534*** **	-0.1169	-0.3002**
		(0.089)	(0.208)	(0.140)	(0.140)
	Coal	0.0801	0.1768	**-0.6682*** **	-0.0291
		(0.081)	(0.140)	(0.193)	(0.202)
	Electricity	-0.2636***	-0.0026	-0.174	**-0.5376*** **
		(0.051)	(0.077)	(0.112)	(0.131)
Almost Ideal	Oil	**-0.1089* **	-0.1781***	-0.1452***	-0.4602***
		(0.065)	(0.050)	(0.037)	(0.075)
	Natural Gas	-0.2541***	**-0.5795*** **	-0.2333***	-0.4197***
		(0.035)	(0.048)	(0.036)	(0.056)
	Coal	-0.033	0.0158	**-0.2375*** **	-0.3257***
		(0.060)	(0.044)	(0.039)	(0.081)
	Electricity	-0.2473***	-0.1493***	-0.4186***	**-0.3192*** **
		(0.028)	(0.032)	(0.030)	(0.048)

Note: the number at the intersection of two commodities represents the cross price elasticity for the commodity on the left resulting from a price change in the commodity given by the column headings. Diagonal elements give own price elasticities. Standard errors are in parenthesis below the elasticity value. All elasticities are calculated at the average prices and quantities over the observed timeframe. (*), (**), and (***) indicates statistical significance at the 10%, 5%, and 1% levels.

Table 2.3 - Wealth Elasticities for Both LA/GAI and LA/AI.

	Commodity	Wealth Elasticity	Std. Err.
Generalized	Oil	1.1038***	0.123
	Natural Gas	1.7923***	0.225
	Coal	0.4403***	0.176
	Electricity	0.9795***	0.085
Almost Ideal	Oil	0.8924***	0.146
	Natural Gas	1.4866***	0.074
	Coal	0.5804***	0.138
	Electricity	1.1244***	0.063

Note: (*), (**), and (***) indicates statistical significance at the 10%, 5%, and 1% levels.

Table 2.4 - Contract Levels as a Percentage of Average Quantity Demanded

Commodity	Average	Contract	Contract Percentage
Oil	6.563	5.690	87%
Natural Gas	4.216	3.656	87%
Coal	4.425	3.274	74%
Electricity	2.107	1.440	68%

Note: All units are billion barrel of oil equivalent (boe). The "Average" column displays the average quantity demanded for the respective commodities over the observed time frame. The “Contract” column is the endogenously estimated contract level. The “Contract Percentage” is the contract level as a percentage of average quantity demanded.

Table 2.5 – Akaiki and Bayesian Loss Metrics for Both LA/GAI and LA/AI.

Model	Observations	Log likelihood	DF	AIC	BIC
LA/GAI	28	795.54	16	-1559.07	-1537.76
LA/AI	28	758.98	12	-1493.96	-1447.97

Note: The AIC (BIC) column contains the value of the Akaiki (Bayesian) Information Criteria for the specified model

Table 2.6 - R^2 and RMSE for Each Commodity Equation Estimated Using Both LA/AI and LA/GAI.

	LA/AI		LA/GAI	
Commodity	R^2	RMSE	R^2	RMSE
Oil	0.9806	0.00833	0.9994	0.00437
Natural Gas	0.9725	0.008059	0.9994	0.004693
Coal	0.9946	0.005517	0.9997	0.005139
Electricity	0.9828	0.006515	0.9999	0.004313

Table 3.1 – Reservoirs in Que$tor

Region	Country	Onshore	Offshore	Total	Region	Country	Onsh	Offshore	Total
	Algeria	1	0	1		Afghanistan	1	0	1
	Angola	1	1	2		Bahngladesh	1	1	2
	Congo	1	1	2		Brunei	1	1	2
	Egypt	2	2	4		Cambodia	0	1	1
Africa	Gabon	1	1	2		China	27	5	32
	Libya	2	0	2		India	8	7	15
	Madegascar	1	1	2		Indonesia	16	24	40
	Nigeria	1	1	2		Japan	11	5	16
	Tunisia	1	1	2	Far East	Malaysia	0	1	1
	Subtotal	**11**	**8**	**19**		Mongolia	1	0	1
Australia	Australia	3	3	6		Myanmar	3	3	6
	Subtotal	**3**	**3**	**6**		North Korea	0	1	1
	Kazakhstan	2	0	2		Pakistan	0	1	1
	Moldova	2	0	2		Philippines	5	1	6
CIS	Russia	5	7	12		South Korea	0	1	1
	Tajikistan	1	0	1		Taiwan	2	2	4
	Turkmenistan	1	0	1		Thailand	6	0	6
	Ukraine	6	0	6		Vietnam	1	0	1
	Subtotal	**17**	**7**	**24**		**Subtotal**	**83**	**54**	**137**
	Uzbekistan	1	0	1		Argentina	5	3	8
	Albania	1	0	1		Barbados	1	0	1
	Bosnia-Herzegov	1	0	1		Bolivia	3	0	3
	Bulgeria	4	0	4		Brazil	11	14	25
	Croatia	1	0	1		Chile	2	1	3
	Czech Republic	1	0	1		Columbia	8	2	10
	Denmark	1	0	1	Latin	Cuba	2	2	4
	Faroe Islands	0	1	1	America	Ecuador	3	1	4
Europe	France	7	1	8		Guatemala	1	0	1
	Germany	4	2	6		Guyana	1	0	1
	Greece	2	2	4		Mexico	10	4	14
	Hungary	1	0	1		Nicaragua	0	1	1
	Ireland	1	4	5		Peru	6	2	8
	Italy	8	7	15		Suriname	1	0	1
	Latvia	0	1	1		Trinidad and Tobago	1	2	3
	Macedonia	1	0	1		**Subtotal**	**55**	**32**	**87**
	Malta	1	0	1		Venezuela	5	4	9
	Netherlands	1	0	1		Bahrain	1	0	1

Table 3.1 Continued

	Norway	0	3	3
	Poland	1	0	1
	Portugal	1	1	2
	Romania	3	0	3
	Serbia and Montenegro	1	0	1
	Spain	4	5	9
	United Kingdom	5	8	13
	Subtotal	**51**	**35**	**86**
Middle East	Iran	4	2	6
	Iraq	1	0	1
	Israel	3	1	4
	Oman	1	0	1
	Saudi Arabia	1	1	2
	Turkey	4	2	6
	Yemen	3	1	4
	Subtotal	**23**	**11**	**34**
North America	Canada	4	4	8
	United States	3	7	10
	Subtotal	**7**	**11**	**18**
	Total	**250**	**161**	**411**

Table 3.2: Operating and Lifecycle Cost Estimation

	Variable	Lifecycle Cost Coef.	Lifecycle Cost Std. Err.	Operating Cost Coef.	Operating Cost Std. Err.
Onshore	Density	2.10824	3.247069	2.094717*	1.181438
	Depth	0.11171**	0.056014	0.0651126***	0.0203805
	Reservoir Pressure	-0.91181**	0.4004117	-0.4808187***	0.1456888
	Elevation	0.776391**	0.3034689	0.3647722***	0.1104164
	Dimensions	-221.6556***	0.3034689	-128.3666***	9.590256
	Total oil	25.1265***	2.616002	14.25148***	0.9518258
	$(\text{Total Oil})^2$	0.00005***	0.0000097	0.0000122***	0.0000035
	Constant	534.9001***	110.7855	213.5349***	40.30903
Offshore	Density	-28.78609***	8.530702	-11.18806***	3.554716
	Depth	-0.3744166**	0.1471098	-0.1491342**	0.0613002
	Reservoir Pressure	3.998208***	1.173586	1.479914***	0.4890295
	Water Depth	0.6325717***	0.2194769	0.1330714	0.0914553
	Dimensions	-17.33516	86.61364	-84.79935**	36.09162
	Total Oil	12.75725	8.292075	12.78538***	3.45528
	$(\text{Total Oil})^2$	-0.0043879***	0.0005644	-0.0015654***	0.0002352
	Constant	1640.11***	356.897	675.8393***	148.7178

Note: Asterisk *, double asterisk ** and triple asterisk *** denote variables significant at the 10%, 5%, and 1% levels, respectively.

Table 3.3: Total Production Under Each Scenario (Million bbl/yr)

			Decreases in World Demand		
Country	Actual Production 2010	Steady Production 2010	2.5%	5%	10%
Russia	3,748.67	3,660.32	3,584.62	3,584.62	3,480.78
Saudi Arabia	3,652.51	3,652.51	3,652.51	3,652.51	3,652.51
United States	2,742.25	2,742.25	2,742.25	2,643.26	2,551.12
Iran	1,549.42	1,544.88	1,544.88	1,544.88	1,533.68
China	1,485.96	1,467.29	1,444.18	1,411.85	1,311.44
Canada	1,217.79	1,189.63	1,189.63	1,189.63	663.27
Mexico	1,079.74	1,044.32	1,044.32	1,038.66	1,025.28
UAE	1,039.71	1,039.71	1,039.71	1,039.71	1,039.71
Kuwait	915.49	915.49	915.49	915.49	915.49
Venezuela	902.04	902.04	887.59	873.21	873.21
Iraq	897.79	897.79	897.79	897.79	897.79
Nigeria	876.59	876.59	876.59	876.59	876.59
Brazil	780.16	772.31	752.41	703.86	589.02
Angola	675.62	188.71	0.00	0.00	0.00
Algeria	660.32	660.32	660.32	660.32	660.32
Kazakhstan	641.14	641.14	641.14	641.14	641.14
Libya	605.55	605.55	605.55	605.55	605.55
Qatar	572.58	572.58	572.58	572.58	572.58
Norway (North)	515.43	515.43	515.43	515.43	515.43
United Kingdom	488.78	472.06	432.49	338.31	267.37
Azerbaijan	378.42	0.00	0.00	0.00	0.00
Afghanistan	378.42	378.42	0.00	0.00	0.00
Indonesia	359.96	346.47	323.15	301.09	153.80
India	358.04	348.33	323.86	316.74	169.07
Oman	315.57	315.57	315.57	315.57	315.57
Colombia	292.23	291.05	291.05	286.04	286.04
Egypt	268.81	251.58	251.58	251.58	246.22
Norway (South)	264.57	264.57	264.57	264.57	264.57
Malaysia	261.30	261.30	261.30	261.30	261.30

Table 3.3 Continued

Argentina	237.60	214.12	181.93	171.48	171.48
Australia	205.30	191.58	156.19	148.38	148.38
Ecuador	180.71	180.71	180.71	180.71	180.71
Sudan	177.39	177.39	177.39	177.39	177.39
Syria	140.53	140.53	140.53	140.53	140.53
Vietnam	134.89	134.89	134.89	134.89	134.89
Thailand	121.95	108.52	108.52	94.10	52.70
Congo	106.57	106.57	106.57	106.57	106.57
Equitorial Guinea	99.98	99.98	99.98	99.98	99.98
Yemen	96.43	74.86	74.86	74.86	74.86
Denmark	91.05	91.05	91.05	0.00	0.00
Gabon	89.43	89.43	89.43	89.43	89.43
Turkmenistan	78.77	0.00	0.00	0.00	0.00
Turkey	72.36	72.11	72.11	72.11	70.36
Japan	68.18	39.25	23.90	0.00	0.00
Brunei	62.85	62.85	62.85	62.85	62.85
Peru	57.36	57.06	57.06	51.21	51.21
Trinidad and Tobago	53.25	53.25	53.25	31.52	31.52
Madagascar	44.51	44.51	44.51	44.51	44.51
Chad	44.50	44.50	44.50	44.50	44.50
Italy	38.72	20.56	20.56	18.33	0.00
Romania	32.53	32.53	32.53	32.53	32.53
Uzbekistan	31.83	0.00	0.00	0.00	0.00
Cuba	30.18	24.65	24.65	22.83	22.83
Tunisia	29.04	29.04	29.04	6.31	0.00
Bangladesh	28.90	27.27	27.27	27.27	27.27
South Korea	27.28	27.28	27.28	27.28	0.00
Taiwan	18.25	15.89	15.89	0.00	0.00
Cambodia	17.35	17.35	17.35	0.00	0.00
Germany	17.00	16.78	16.78	16.78	16.78
Bahrain	12.26	12.26	12.26	12.26	12.26
Chile	11.54	11.54	3.52	0.00	0.00

Table 3.3 Continued

Ukraine	9.81	8.94	8.94	6.25	4.34
Philippines	9.81	8.54	0.00	0.00	0.00
Myanmar	9.37	6.52	6.52	0.00	0.00
Moldova	7.64	7.64	7.64	7.64	6.04
Suriname	7.52	7.52	7.52	7.52	0.00
Greece	5.53	5.53	5.53	4.30	1.08
Ireland	4.38	0.61	0.61	0.61	0.00
Spain	4.34	0.00	0.00	0.00	0.00
Bulgaria	3.40	3.40	3.40	3.40	2.79
Bolivia	3.09	1.62	1.62	0.00	0.00
Faroe Islands	2.85	2.85	2.85	2.85	2.85
France	2.25	0.79	0.79	0.79	0.00
Hungary	2.24	2.24	2.24	2.24	2.24
Guatemala	1.70	1.70	1.70	0.00	0.00
Latvia	1.41	1.41	0.00	0.00	0.00
Barbados	1.27	0.00	0.00	0.00	0.00
Pakistan	1.12	1.12	1.12	1.12	1.12
Netherlands	0.86	0.86	0.86	0.86	0.00
Croatia	0.57	0.57	0.57	0.57	0.00
Mongolia	0.55	0.55	0.00	0.00	0.00
Serbia and Montenegro	0.54	0.54	0.54	0.54	0.54
Tajikistan	0.31	0.00	0.00	0.00	0.00
Czech Republic	0.24	0.00	0.00	0.00	0.00
Poland	0.22	0.00	0.00	0.00	0.00
Total Production	30,464.36	29,099.46	28,210.37	27,629.56	26,183.39
Price (U.S. Dollars)	$67.34		$47.05	$31.83	$21.33

"Steady Production" refers to the total amount of oil that is cost feasible if the price of $67.34 per barrel were to persist. It is, therefore, the oil that can be produced at a lifetime cost per barrel of less than $67.34, as opposed to "Actual Production 2010", which is the oil that can be produced at an operating cost per barrel of less than $67.34. The last row labeled "Price" displays the market price for a barrel of oil under each scenario.

Table 3.4: Percentage Change in Per Capita GDP Under Each Scenario

Country	2010 Oil Revenue	2010 Oil Revenue as Percent of GDP	2.5%	5%	10%	Per Capita GDP	Population	GDP (1000s)
Afghanistan	$25,484,032,271	83.77%	-83.77%	-83.77%	-83.77%	$1,000	30,419,928	$30,419,928
Kuwait	$61,651,842,305	55.87%	-16.84%	-29.46%	-38.17%	$41,700	2,646,314	$110,351,294
Libya	$40,779,484,333	51.52%	-15.53%	-27.17%	-35.20%	$14,100	5,613,380	$79,148,658
Equitorial Guinea	$6,733,244,587	50.86%	-15.33%	-26.82%	-34.75%	$19,300	685,991	$13,239,626
Iraq	$60,460,018,790	49.80%	-15.01%	-26.26%	-34.03%	$3,900	31,129,225	$121,403,978
Angola	$45,498,724,866	42.00%	-42.00%	-42.00%	-42.00%	$6,000	18,056,072	$108,336,432
Saudi Arabia	$245,971,605,944	37.84%	-11.40%	-19.95%	-25.85%	$24,500	26,534,504	$650,095,348
Congo	$7,176,962,968	35.73%	-10.77%	-18.84%	-24.42%	$4,600	4,366,266	$20,084,824
UAE	$70,017,246,930	27.62%	-8.32%	-14.57%	-18.87%	$47,700	5,314,317	$253,492,921
Azerbaijan	$25,484,033,618	26.32%	-26.32%	-26.32%	-26.32%	$10,200	9,493,600	$96,834,720
Oman	$21,251,347,431	25.57%	-7.70%	-13.48%	-17.47%	$26,900	3,090,150	$83,125,035
Gabon	$6,022,162,399	22.83%	-6.88%	-12.04%	-15.60%	$16,400	1,608,321	$26,376,464
Brunei	$4,232,432,420	20.71%	-6.24%	-10.92%	-14.15%	$50,000	408,786	$20,439,300
Norway	$52,527,629,198	20.59%	-6.20%	-10.86%	-14.07%	$54,200	4,707,270	$255,134,034
Qatar	$38,559,602,665	19.98%	-6.02%	-10.54%	-13.65%	$98,900	1,951,591	$193,012,350
Kazakhstan	$43,176,673,999	18.67%	-5.63%	-9.84%	-12.75%	$13,200	17,522,010	$231,290,532
Venezuela	$60,746,227,245	17.05%	-5.33%	-9.25%	-11.82%	$12,700	28,047,938	$356,208,813
Algeria	$44,467,881,980	16.08%	-4.85%	-8.48%	-10.99%	$7,400	37,367,226	$276,517,472
Madagascar	$2,997,359,651	15.13%	-4.56%	-7.98%	-10.34%	$900	22,005,222	$19,804,700
Trinidad and Tobago	$3,585,917,057	14.40%	-4.34%	-10.37%	-11.70%	$20,300	1,226,383	$24,895,575
Chad	$2,996,770,777	14.37%	-4.33%	-7.58%	-9.82%	$1,900	10,975,648	$20,853,731
Nigeria	$59,032,343,718	13.35%	-4.02%	-7.04%	-9.12%	$2,600	170,123,740	$442,321,724
Turkmenistan	$5,304,677,059	13.28%	-13.28%	-13.28%	-13.28%	$7,900	5,054,828	$39,933,141
Sudan	$11,946,003,780	12.93%	-3.90%	-6.82%	-8.84%	$2,700	34,206,710	$92,358,117
Faroe Islands	$192,234,459	12.74%	-3.84%	-6.72%	-8.70%	$30,500	49,483	$1,509,232
Yemen	$6,493,833,916	11.40%	-5.22%	-7.22%	-8.59%	$2,300	24,771,809	$56,975,161
Russia	$252,447,566,236	10.42%	-3.46%	-5.71%	-7.36%	$17,000	142,517,670	$2,422,800,390
Iran	$104,342,837,043	10.02%	-3.04%	-5.30%	-6.88%	$13,200	78,868,711	$1,041,066,985
Suriname	$506,152,579	9.41%	-2.84%	-4.96%	-9.41%	$9,600	560,157	$5,377,507
Ecuador	$12,169,364,804	9.30%	-2.80%	-4.90%	-6.35%	$8,600	15,223,680	$130,923,648
Syria	$9,463,466,881	8.24%	-2.48%	-4.34%	-5.63%	$5,100	22,530,746	$114,906,805
Canada	$82,009,641,920	5.82%	-1.85%	-3.13%	-4.81%	$41,100	34,300,083	$1,409,733,411
Mexico	$72,713,309,429	4.27%	-1.39%	-2.33%	-2.99%	$14,800	114,975,406	$1,701,636,009

Table 3.4 Continued

Columbia	$19,679,885,956	4.18%	-1.27%	-2.25%	-2.89%	$10,400	45,239,079	$470,486,422
Moldova	$514,386,887	4.14%	-1.25%	-2.18%	-3.10%	$3,400	3,656,843	$12,433,266
Malaysia	$17,596,835,976	3.82%	-1.15%	-2.01%	-2.61%	$15,800	29,179,952	$461,043,242
Cambodia	$1,168,250,964	3.55%	-1.07%	-3.55%	-3.55%	$2,200	14,952,665	$32,895,863
Egypt	$18,102,649,130	3.28%	-1.13%	-1.83%	-2.33%	$6,600	83,688,164	$552,341,882
Denmark	$6,131,780,519	2.94%	-0.89%	-2.94%	-2.94%	$37,600	5,543,453	$208,433,833
Vietnam	$9,083,631,583	2.92%	-0.88%	-1.54%	-1.99%	$3,400	91,519,289	$311,165,583
Bahrain	$825,886,273	2.37%	-0.71%	-1.25%	-1.62%	$27,900	1,248,348	$34,828,909
Uzbekistan	$2,143,465,552	2.29%	-2.29%	-2.29%	-2.29%	$3,300	28,394,180	$93,700,794
Brazil	$52,538,181,209	2.22%	-0.72%	-1.27%	-1.69%	$11,900	199,321,413	$2,371,924,815
Argentina	$16,000,748,014	2.14%	-1.00%	-1.41%	-1.65%	$17,700	42,192,494	$746,807,144
Indonesia	$24,240,697,344	2.07%	-0.77%	-1.25%	-1.79%	$4,700	248,645,008	$1,168,631,538
Tunisia	$1,955,834,464	1.90%	-0.57%	-1.70%	-1.90%	$9,600	10,732,900	$103,035,840
Cuba	$2,032,093,785	1.85%	-0.80%	-1.19%	-1.41%	$9,900	11,075,244	$109,644,916
Australia	$13,825,305,260	1.54%	-0.72%	-1.01%	-1.19%	$40,800	22,015,576	$898,235,501
United Kingdom	$32,916,119,427	1.43%	-0.54%	-0.96%	-1.18%	$36,600	63,047,162	$2,307,526,129
Thailand	$8,212,451,694	1.29%	-0.49%	-0.82%	-1.11%	$9,500	67,091,089	$637,365,346
Peru	$3,863,004,916	1.28%	-0.39%	-0.74%	-0.92%	$10,200	29,549,517	$301,405,073
Barbados	$85,335,536	1.25%	-1.25%	-1.25%	-1.25%	$23,700	287,733	$6,819,272
US	$184,671,453,499	1.20%	-0.36%	-0.65%	-0.85%	$49,000	313,847,465	$15,378,525,785
Myanmar	$631,227,686	0.89%	-0.46%	-0.89%	-0.89%	$1,300	54,584,650	$70,960,045
China	$100,069,247,292	0.88%	-0.28%	-0.48%	-0.63%	$8,500	1,343,239,923	$11,417,539,346
Romania	$2,190,597,686	0.80%	-0.24%	-0.42%	-0.54%	$12,600	21,848,504	$275,291,150
Bangladesh	$1,946,018,841	0.71%	-0.24%	-0.39%	-0.50%	$1,700	161,083,804	$273,842,467
India	$24,111,479,078	0.54%	-0.20%	-0.31%	-0.46%	$3,700	1,205,073,612	$4,458,772,364
Turkey	$4,872,931,506	0.42%	-0.13%	-0.22%	-0.29%	$14,700	79,749,461	$1,172,317,077
Bolivia	$208,046,713	0.41%	-0.26%	-0.41%	-0.41%	$4,900	10,290,003	$50,421,015
Latvia	$95,263,628	0.27%	-0.27%	-0.27%	-0.27%	$15,900	2,191,580	$34,846,122
Chile	$777,281,041	0.26%	-0.21%	-0.26%	-0.26%	$17,400	17,067,369	$296,972,221
Mongolia	$37,127,538	0.24%	-0.24%	-0.24%	-0.24%	$4,800	3,179,997	$15,263,986
Bulgaria	$229,182,437	0.24%	-0.07%	-0.12%	-0.17%	$13,800	7,037,935	$97,123,503
Ukraine	$660,439,235	0.20%	-0.07%	-0.14%	-0.17%	$7,300	44,854,065	$327,434,675
Guatemala	$114,772,988	0.16%	-0.05%	-0.16%	-0.16%	$5,100	14,099,032	$71,905,063
Ireland	$295,141,829	0.16%	-0.14%	-0.15%	-0.16%	$40,100	4,722,028	$189,353,323
Philippines	$660,303,121	0.16%	-0.16%	-0.16%	-0.16%	$4,100	103,775,002	$425,477,508
Taiwan	$1,229,018,623	0.14%	-0.05%	-0.14%	-0.14%	$38,200	23,234,936	$887,574,555
Italy	$2,607,531,670	0.14%	-0.09%	-0.11%	-0.14%	$30,900	61,261,254	$1,892,972,749
Greece	$372,297,494	0.13%	-0.04%	-0.08%	-0.12%	$26,600	10,767,827	$286,424,198

Table 3.4 Continued

Tajikistan	$20,759,929	0.13%	-0.13%	-0.13%	-0.13%	$2,100	7,768,385	$16,313,609
South Korea	$1,836,985,961	0.12%	-0.04%	-0.06%	-0.12%	$32,100	48,860,500	$1,568,422,050
Japan	$4,591,476,338	0.10%	-0.08%	-0.10%	-0.10%	$35,200	127,368,088	$4,483,356,698
Hungary	$150,664,876	0.08%	-0.02%	-0.04%	-0.05%	$19,800	9,958,453	$197,177,369
Serbia and Montenegro	$36,606,616	0.05%	-0.01%	-0.02%	-0.03%	$10,800	7,276,604	$78,587,323
Croatia	$38,254,624	0.05%	-0.01%	-0.02%	-0.05%	$18,400	4,480,043	$82,432,791
Germany	$1,144,557,513	0.04%	-0.01%	-0.02%	-0.03%	$38,400	81,305,856	$3,122,144,870
Spain	$292,445,662	0.02%	-0.02%	-0.02%	-0.02%	$31,000	47,042,984	$1,458,332,504
Pakistan	$75,335,597	0.01%	0.00%	-0.01%	-0.01%	$2,800	190,291,129	$532,815,161
Netherlands	$57,928,904	0.01%	0.00%	0.00%	-0.01%	$42,700	16,730,632	$714,397,986
France	$151,383,117	0.01%	0.00%	-0.01%	-0.01%	$35,600	65,630,692	$2,336,452,635
Czech Republic	$16,298,547	0.01%	-0.01%	-0.01%	-0.01%	$27,400	10,177,300	$278,858,020
Poland	$14,917,314	0.00%	0.00%	0.00%	0.00%	$20,600	38,415,284	$791,354,850

Sorted by “2010 Oil Revenue as Percentage of GDP”

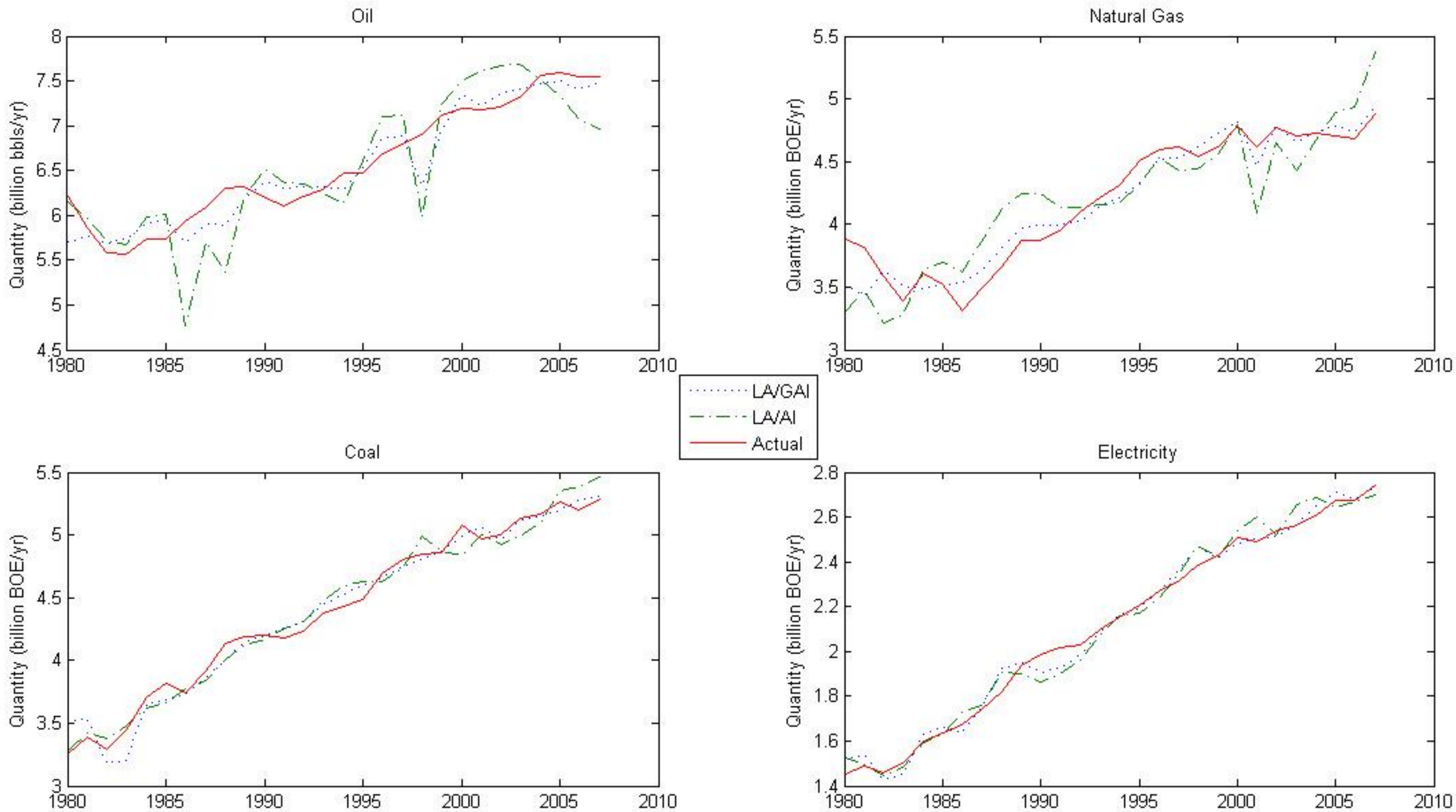
Table 3.5: Change in "U.S. Oil Independence" Under Each Scenario

Scenario	Source of Demand Reduction	U.S. Consumption (Million Bbl/Yr)	Domestic Production (Million Bbl/Yr)	Percentage Met Domestically	Percentage Change
Baseline		6989.07	2742.25	39.24%	-
2.5%	All U.S.	6290.17	2742.25	43.60%	11.11%
	Proportional	6814.35		40.24%	2.56%
5%	All U.S.	5591.26	2643.26	47.27%	20.49%
	Proportional	6639.62		39.81%	1.46%
10%	All U.S.	4193.44	2551.12	60.84%	55.05%
	Proportional	6290.17		40.56%	3.37%

Note: For each scenario "All U.S." means that the entire reduction in world demand of 2.5%, 5%, or 10% came from the U.S. In 2010 the U.S. consumed approximately 25% of the world's produced oil. To reduce world demand by 5%, the U.S. would need to reduce demand by 20% (20% x 25% = 5%). For each scenario "Proportional" means that world demand is reduced by the same percentage as world demand (i.e., 2.5%, 5%, or 10%) "Percentage Met Domestically" is "Domestic Production" divided by "U.S. Consumption".

APPENDIX II

FIGURES



Note: "Actual" is the actual U.S. consumption of the commodity. LA/AI (LA/GAI) represents the Linear Approximate (Generalized) Almost Ideal estimate for the year. BOE stands for barrels of oil equivalent.

Figure 2.1 – In Sample Estimates for Oil, Natural Gas, Coal, and Electricity Using LA/GAI and LA/AI Compared to Actual Consumption

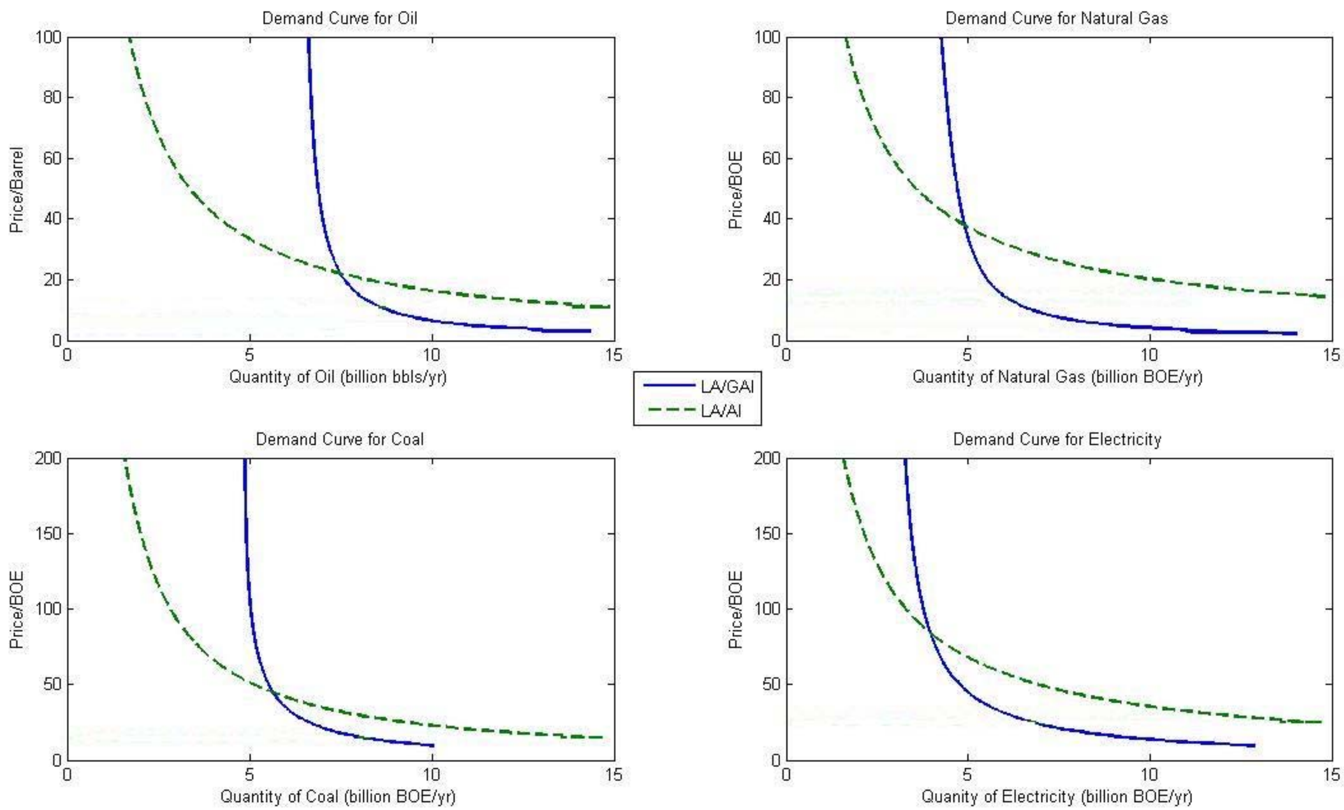


Figure 2.2 – Demand Curves for Each Commodity with LA/GAI and LA/AI

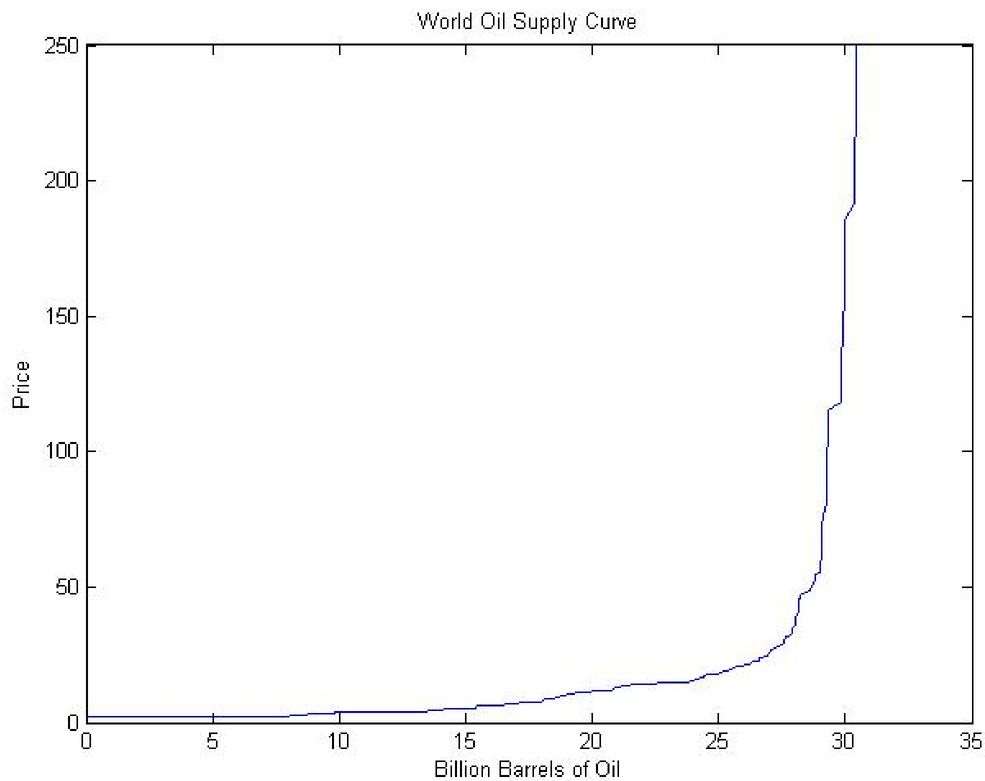


Figure 3.1: World Oil Supply Curve

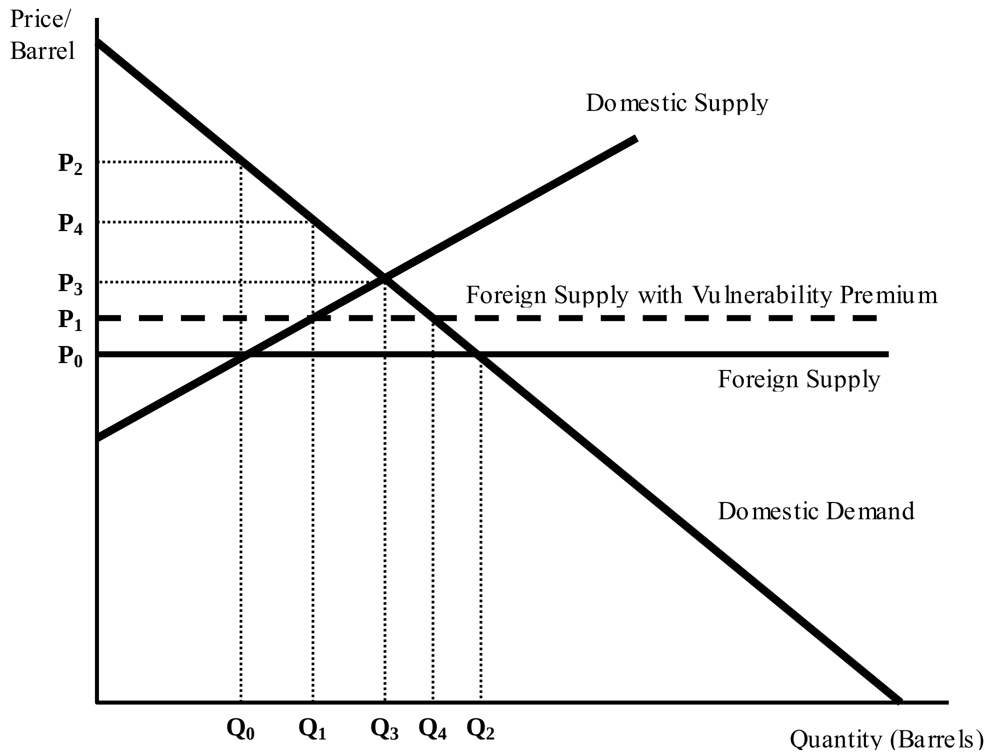


Figure 4.1 – Illustration of Vulnerability Premium with Foreign Trade

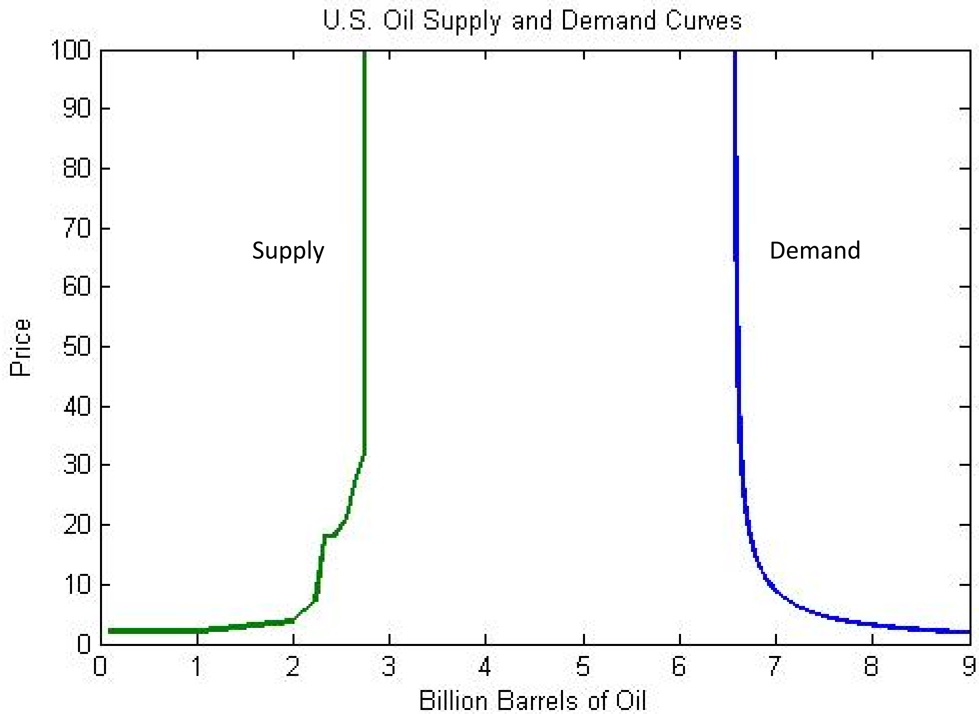


Figure 4.2: U.S. Oil Supply and Demand Curves