The Economics of Energy Security

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Abstract

Energy security is the ability of households, businesses, and government to accommodate disruptions in supply in energy markets. This survey considers the economic dimensions of energy security and political and other noneconomic security concerns and discusses policy approaches that could enhance US energy security. A number of points emerge. First, energy security is enhanced by reducing consumption, not imports. A policy to eliminate oil imports, for example, will not enhance US energy security, whereas policies to reduce energy consumption can improve energy security. Second, energy security is distinct from considerations of energy externalities. Energy security taxes are appealing on political grounds but are more difficult to justify on economic grounds. Finally, the contrasting concerns over energy security between policy makers and economists are striking. The article notes some possible reasons for these differing views and suggests possible research opportunities in this area.

1. INTRODUCTION

In the early days of the 1973 OPEC oil embargo, Richard Nixon set, as a national goal,

> . . .in the spirit of Apollo, with the determination of the Manhattan Project, that by the end of this decade we will have developed the potential to meet our own energy needs without depending on any foreign energy sources. Let us pledge that by 1980, under Project Independence, we shall be able to meet America's energy needs from America's own energy resources. (Nixon 1973)

Energy security has been a major policy agenda item for every subsequent US president since that time.

The divergence in views and importance placed on this issue between economists and politicians is striking. This review considers the topic of energy security from an economic perspective. In Section 2, I review and critique the major economic concerns around energy markets that—loosely speaking—are lumped under the umbrella of energy security. Section 3 reviews various broader energy security considerations that go beyond standard economic considerations. In Section 4, I review various policy options that have been suggested to address energy security concerns. In a concluding section, I return to the issue of the differing perspectives between politicians and economists and ask whether the latter group is missing something fundamental in its analysis of energy security.

A common definition of energy security is the "availability of sufficient supplies at affordable prices" (Yergin 2006). Such a definition is both intuitive and elusive. What do we mean by "sufficient supplies"? What is an "affordable" price? In 2013, many Europeans managed to pay the equivalent of roughly $8 per gallon for premium gasoline without suffering severe economic hardship; in contrast, a price of less than $4 a gallon held in the United States at that time.[1] Although a price of $8 per gallon may be manageable in the long run, the short-run economic dislocations to the US economy of a rapid price increase from the 2013 US price to a European price of $8 would likely be significant. And at either price, low-income households may struggle to cover their energy costs; the higher the price is, the more difficult covering costs becomes for an increasing share of households. But a definition based on the notion of affordability may be more useful for political rhetoric than for economic analysis.

The Congressional Budget Office (2012) defines energy security as "the ability of US households and businesses to accommodate disruptions of supply in energy markets." This definition emphasizes the relation between energy access and household and business activity. The definition does not address the ability of the US government to accommodate energy supply disruptions. A major concern for policy makers is the availability of adequate fuel supplies to accomplish military missions and to respond to possible foreign threats. I discuss the issue of energy and national security below and argue that it is an important element of energy security, although perhaps not in ways in which policy makers often invoke it. For the purposes of this review, I define energy security as the ability of US households, businesses, and governments to accommodate disruptions of supply in energy markets.[2]

[1]Energy prices are taken from IEA (2013).

[2]Many other approaches to defining and measuring energy security exist. Sovacool (2011), for example, defines an index along 20 dimensions with 200 attributes. In subsequent work, Sovacool & Mukherjee (2011) reduce the number of dimensions to 5 and the number of attributes to 20. Sovacool (2013) applies the index to a set of countries and finds that Japan has the highest energy security index among the 18 countries considered. The impact of the Fukushima nuclear accident on Japan's energy system and economy suggests the difficulty with constructing robust energy security indexes.

One area of general confusion related to energy security is that of energy consumption versus imports. This confusion is most common in policy discussions related to oil dependence, as typified by the quotation at the beginning of this article (Nixon 1973). Reducing oil imports is often viewed as an important policy imperative. The view is that reduced reliance on foreign oil suppliers will protect us from price shocks arising from foreign oil supply curtailments. The flaw in this reasoning is that oil is a fungible commodity, with oil prices equilibrating worldwide. Even if the United States imported no oil but rather relied on domestic production for all its oil needs, a supply shock elsewhere in the world would lead to a rise in domestic oil prices. This reality simply follows from the ability of domestic producers to divert oil from domestic markets to foreign markets as oil prices rise elsewhere. The domestic price would also have to rise to reequilibrate domestic supply and demand.[3] Energy independence, properly understood, depends on reducing energy (or, more specifically, oil) consumption rather than imports.

A second area of potential confusion is the relationship between energy security and externalities. An economic externality is the impact of an economic agent's action on other agents when this impact is transmitted outside of market mechanisms. Pollution associated with energy consumption is a classic externality. In the absence of strong conditions on the ability of economic agents to bargain (see Coase 1960), markets outcomes will be inefficient. Efficiency requires that in equilibrium the social marginal benefits of energy use equal the social marginal costs. If we assume that all benefits of energy use are private, efficiency is ensured when the price of energy equals its social marginal cost, the sum of the private marginal costs of production and the external damages from energy use. One way to achieve an efficient market outcome is to set a tax equal to the social marginal damages of pollution. Such a tax is termed a Pigouvian tax (Pigou 1932). Whether an energy security externality exists is an issue of some confusion. Following the logic of a recent report of the National Research Council (2009), I argue below that there is little if any externality associated with energy production or consumption arising from energy security considerations. The implication is that there is little potential for Pareto improvements by levying an energy security tax on energy products.[4] That energy security is not an externality is distinct from concerns about energy security that may give rise to other policy responses. I discuss policy implications in Section 4 below.

A final area of potential confusion is the conflation of energy security and low prices. Low prices may be attractive to consumers—as low prices for any commodity always are—but a goal of low prices does not follow from the definition of energy security used in this article. Low prices may in fact undermine activities that protect against supply disruptions. Low prices, for example, undermine incentives for investments in energy efficiency that reduce reliance on energy. Low prices may also remove sources of revenue that deter investors from upgrading or expanding energy infrastructure that could enhance the reliability of the energy system.

2. AN ECONOMIC PERSPECTIVE ON ENERGY SECURITY

How important is energy in the US economy? One metric is the amount of energy used per dollar of GDP in the US economy. **Figure 1** graphs energy intensity (energy measured in BTUs per dollar of real GDP) from 1900 to the present.

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[3]This price equilibration is limited by the fact that domestically produced oil, in most cases, cannot be exported. Congress is under pressure to remove this export ban given the dramatic growth in US oil production.

[4]This implication is true in a global sense. As I discuss below, a tax can improve domestic welfare at the cost of lowered welfare in other countries.

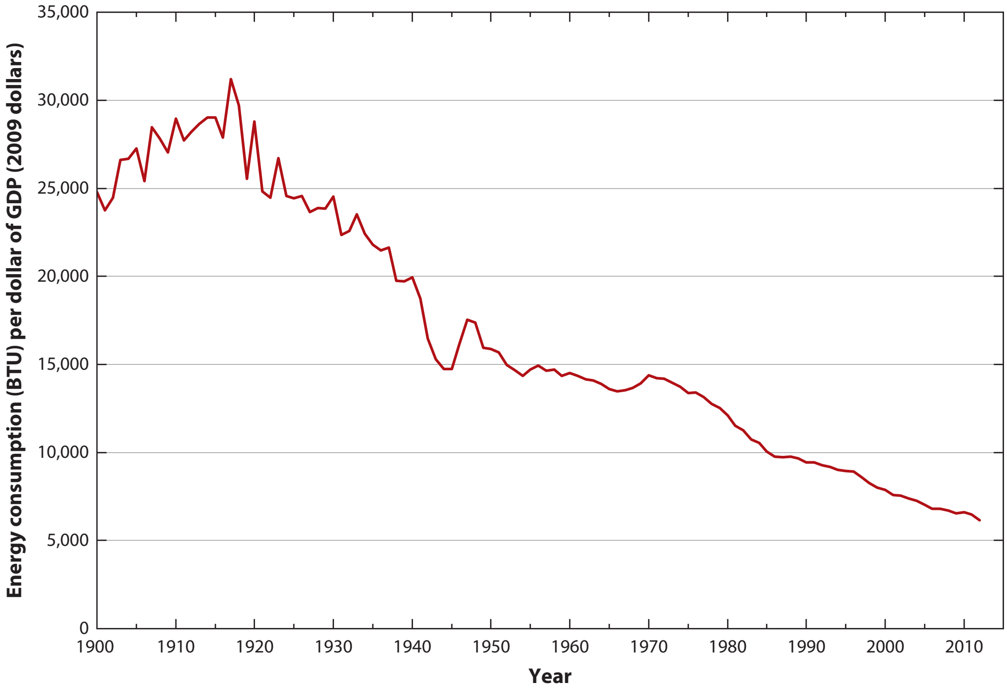

Figure 1

US aggregate energy intensity, 1900–2012. GDP data are from Federal Reserve Economic Data (FRED), series GDPCA. Data are available at **http://research.stlouisfed.org/fred2/**. GNP data prior to 1929 are from Schurr & Netschert (1960, p. 524), table XIII. For energy consumption data, data prior to 1949 are from Schurr & Netschert (1960, p. 512), table VII; 1949–2011 data are from Energy Information Administration (EIA) *Annual Energy Review*, table 1.3 (**http://www.eia.gov/totalenergy/data/annual/index.cfm**); and 2012 data are from EIA *Monthly Energy Review*, table 1.3 (**http://www.eia.gov/totalenergy/data/monthly/index.cfm**).

Energy intensity has fallen steadily from a peak of more than 30,000 BTUs per dollar of real GDP in 1917 to slightly more than 6,000 BTUs per dollar of real GDP in 2012, a decline of nearly 80%. Metcalf (2006) discusses the major drivers of the sharp decline in energy intensity over the past century. An important point emerging from **Figure 1** is that improvements in energy intensity are not entirely a post–oil shock phenomenon. Although energy intensity fell at a rate of 1.9% after 1970, it fell at a rate of 0.9% between 1931 and 1970. The acceleration in the rate of decline following the 1970s oil shocks suggests the sensitivity of energy intensity to economic forces.[5]

Figure 1 obscures important differences among fuels. Oil, for example, is a dominant fuel for transportation, whereas coal is used primarily in electricity production, in which it competes with natural gas and other sources. **Figure 2** shows changes in energy intensity for petroleum, natural gas, and coal between 1950 and 2012.

Petroleum intensity was more than twice as high as natural gas intensity in 1950, but the intensity of the two fuels nearly converged over the next 61 years. With the boom in domestic natural gas production along with more stringent fuel economy standards finalized in 2012, petroleum intensity may fall to less than the intensity of natural gas within the next decade. The intensity of coal use in 1950 was comparable to that of petroleum but rapidly fell between 1950 and 1980.

[5]Metcalf (2008) explores the drivers of changes in energy intensity at the state level.

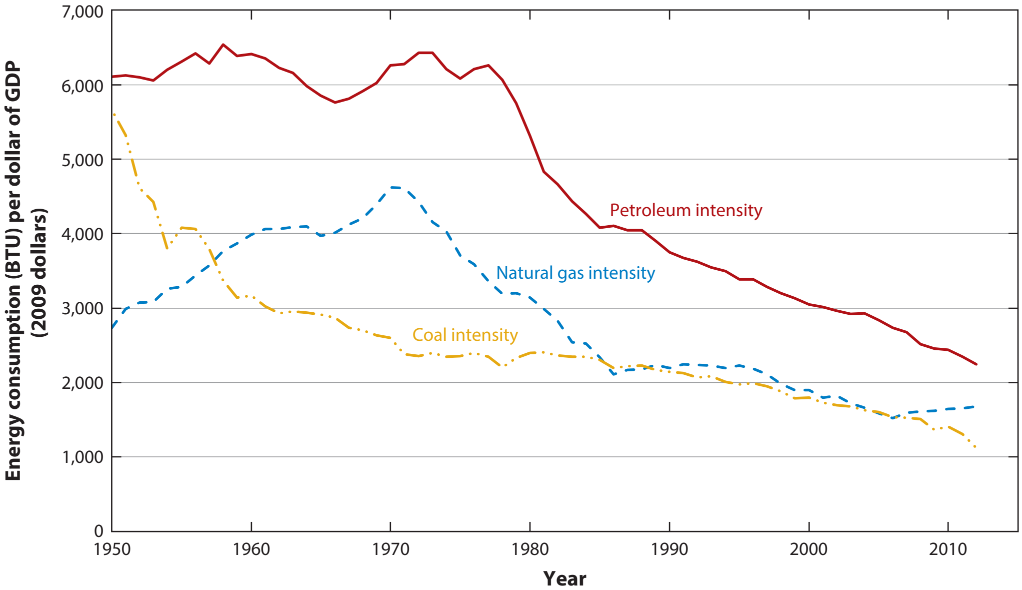

Figure 2

Fossil fuel intensity, 1950–2012. GDP data are from FRED, series GDPCA. Data are available at **http://research.stlouisfed.org/fred2/**. For energy consumption data, data up to 2011 are from Energy Information Administration (EIA) *Annual Energy Review*, table 1.3 (**http://www.eia.gov/totalenergy/data/annual/index.cfm**), and 2012 data are from EIA *Monthly Energy Review*, table 1.3 (**http://www.eia.gov/totalenergy/data/monthly/index.cfm**).

Since 1980, the intensity of coal use closely tracked the intensity of natural gas until the past 5 or so years, with the hydrofracking boom in the United States.

These numbers illustrate that our economy is significantly more efficient in using energy than it was before the first oil embargo. If we hold other factors constant, the United States should be less vulnerable to disruption in energy markets. This reduced vulnerability should not make us complacent, however, as the combination of the high oil prices in the mid-2000s along with the onset of the Great Recession demonstrated the ability of energy markets to harm the US economy, as Hamilton (2009) argues.

Energy intensity is a useful metric for measuring improvements in energy efficiency. But what we really care about are measures of the impact on the economy of supply disruptions. I turn to that topic next. The literature on the economics of energy security has focused primarily on two key considerations: the impact of supply shocks on the economy and terms-of-trade effects associated with oil imports (Toman 1993).

2.1. Supply Shocks and the Macroeconomy

I begin with a simple analysis of the impact of supply shocks on the US economy (Hamilton 2008). Consider a simple production function relating a firm's output to inputs:

$$Y = F(K, L, E). \tag{1}$$

Output (Y) is a function of capital (K), labor (L), and energy (E) used in the production of final goods and services. If output is sold at nominal price p; if the cost of inputs is w, r, and q for labor, capital, and energy, respectively; and if we assume constant-returns-to-scale technology, then

$$pY = wL + rK + qE. \tag{2}$$

Profit-maximizing firms set the value of marginal product for each factor equal to the input price, or

$$p\frac{\partial Y}{\partial E} = q, \tag{3}$$

which can be rewritten as

$$\frac{\partial \ln Y}{\partial \ln E} = \frac{qE}{pY}. \tag{4}$$

The elasticity of the firm's output to energy use is equal to the share of energy in the firm's revenue. By analogy to the US economy, a 1% curtailment in energy would be expected to lead to a real output decline equal to the share of energy spending in GDP. Consider an oil supply shock. **Figure 3** provides the historic share of oil expenditures as a percentage of GDP.

The share has been in the 2–3% range, except during price spikes. A 4% share is not unusual; the share rose to nearly 6% in 2008 but quickly dropped back. If we assume a 5% oil share (generous), then a supply shock of 10% should lead to a drop in the value of real output of 0.5%.

Table 1 (based on a table in Hamilton 2008) shows a number of disruptions to world oil supply along with the associated impact on US real GDP. The counterfactual GDP growth is approximately

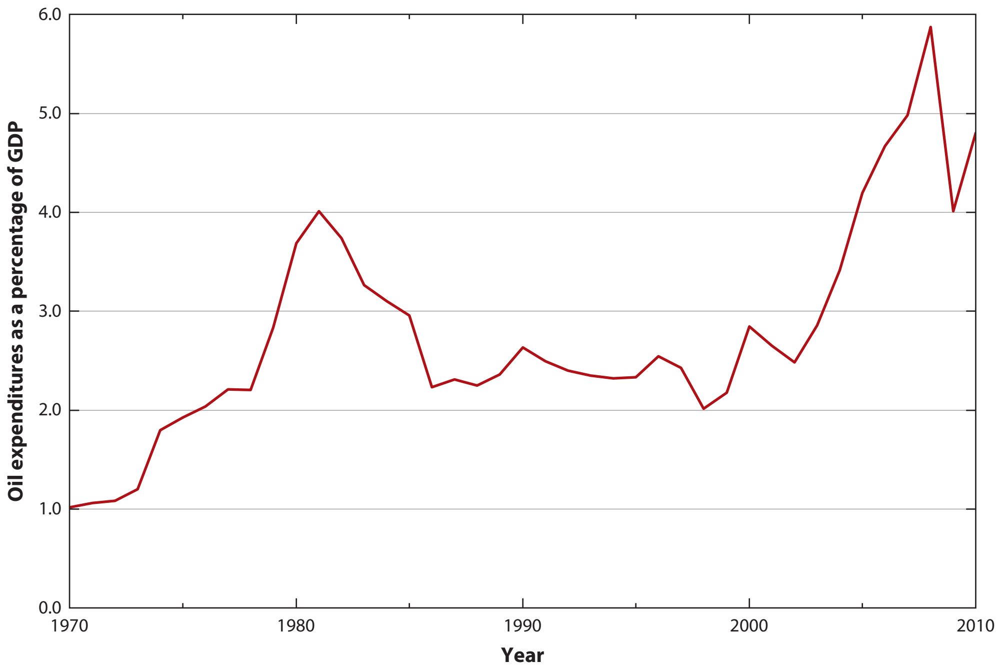

Figure 3

Share of oil in GDP, 1970–2010. GDP data are from FRED, series GDPCA. Oil expenditure data are from Energy Information Administration *Annual Energy Review*, table 3.5 (**http://www.eia.gov/totalenergy/data/annual/index.cfm**).

Table 1 Exogenous disruptions in world petroleum supply, 1956–1990

Date	Event	Drop as percentage of world production	Change in US real GDP (%)
Nov. 1956	Suez crisis	10.1	−2.5
Nov. 1973	Arab–Israel war	7.8	−3.2
Nov. 1978	Iranian revolution	8.9	−0.6
Oct. 1980	Iran–Iraq war	7.2	−0.5
Aug. 1990	Persian Gulf war	8.8	−0.1

From Hamilton (2008).

3.4% per year. So we're seeing an impact of a 7- to 10-percentage-point supply curtailment on GDP in the range of 4–5%—an order of magnitude higher than what theory suggests should occur.

One should not make too much of this simple analysis for a number of reasons, including the lack of a carefully constructed counterfactual. But it is suggestive that oil supply shocks have outsized impacts on the economy. Hamilton (2008) discusses various explanations of this large impact of oil shocks on macroeconomic performance. The important point is that, despite the small share of oil in GDP, energy in general and oil in particular can have large impacts on economic performance. Whether the impact of oil shocks on the economy is as large as it once was is a matter of considerable academic analysis. Analyses focus on factors such as the role of improved monetary policy response to oil shocks combined with a decreasing importance of oil in the economy (Nordhaus 2007), the interplay between oil markets and other sectors (e.g., housing and automobiles) (Hamilton 2009), and the need to distinguish between supply and demand shocks (Kilian 2008). Despite (or perhaps because of) the lack of consensus among economists on the macroeconomic impact of energy supply shocks, policy makers place great importance on supply stability as an economic stabilizing force.

2.2. Energy Imports

The reliance on imported oil in the United States has historically been a source of concern with respect to energy security. The notion of an energy security price premium is associated with the potential monopsony power of US consumers in aggregate. The United States accounts for some 20% of global oil consumption. The increased demand for one more barrel of oil by a large consumer drives up the world price of oil and so raises the cost of all inframarginal barrels of imported oil. Thus, the social cost of oil (from a US point of view) is the price of oil along with the incremental cost of oil imports from this marginal import.[6] Because the United States is such a large consumer, any US policy to reduce domestic oil demand reduces the world oil price and benefits the United States through lower prices on inframarginal oil imports. Setting a tax on oil equal to the price wedge, so the argument goes, would internalize this apparent externality.

Figure 4 illustrates how such a tax would work.[7] The aggregate demand for oil is given by the downward-sloping curve marked *D*. With an upward-sloping supply curve for oil, the market

[6]The concern here is with imports because a rise in the price of domestic oil simply induces an income transfer from one US resident to another.

[7]This discussion draws heavily on the discussion in National Research Council (2009). The author served on the panel writing that report and was a member of the subgroup focusing on energy security issues.

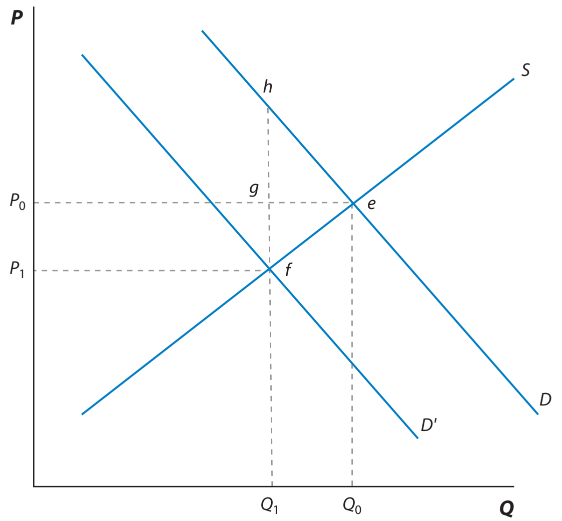

Figure 4

Monopsony power. Key: D, aggregate demand; S, aggregate supply; P, price per barrel of oil; Q, barrels of oil consumed; e, market equilibrium for Q_0 consumption and P_0 price; f, market equilibrium for Q_1 consumption and P_1 price.

equilibrium occurs at point e, where Q_0 barrels of oil are consumed at price per barrel P_0. A domestic tax of fh shifts the oil demand curve from D to D' and leads to a drop in the world oil price from P_0 to P_1. The gain to consumers from the fall in oil price is the rectangle P_0P_1fg. This gain is offset by losses to producers in oil revenue (equal to the same rectangle). If all supply comes from domestic production, there is no gain to the United States. The gain to producers is exactly offset by the loss to US producers (if deadweight loss considerations are ignored). If all supply comes from non-US producers, the gain to US consumers is financed by a transfer from other oil-producing countries. The marginal oil premium is the incremental income transfer to US consumers from foreign producers due to a small reduction in the demand for oil arising from a US oil consumption tax.

A policy to take advantage of consumer purchasing power generates a transfer from foreign oil-producing nations to the United States. Such a beggar-thy-neighbor policy has been justified on the grounds that OPEC is artificially inflating world oil prices at the expense of consuming nations and that the exercise of monopsony power is a countervailing policy (e.g., Broadman & Hogan 1988). This situation is an example of a pecuniary externality (Bohi & Toman 1993).

The steady and rapidly rising share of oil imports in consumption in the postwar period (**Figure 5**) combined with the 1973 Arab oil embargo certainly helps explain interest in the monopsony pricing argument. Reliance on foreign oil peaked in 2005 and has fallen by roughly 15 percentage points since then with the boom in domestic oil production.

The National Research Council (2009) report on energy externalities considers in some depth whether the market power of large consumers should be viewed as an externality. The report notes that "[e]xternalities create a market failure. Exercising monopsony power creates a market failure where one did not exist before" (p. 329). The report acknowledges that the United States could exercise its monopsony power to make its citizens better off but also flags the issue of supplier response to the exercise of market power by consumers. A dominant producer or cartel might choose to withhold supply from the market to act as a countervailing force to the price-depressing behavior of monopsonists. Whether there is an effective cartel that could exercise this power is an

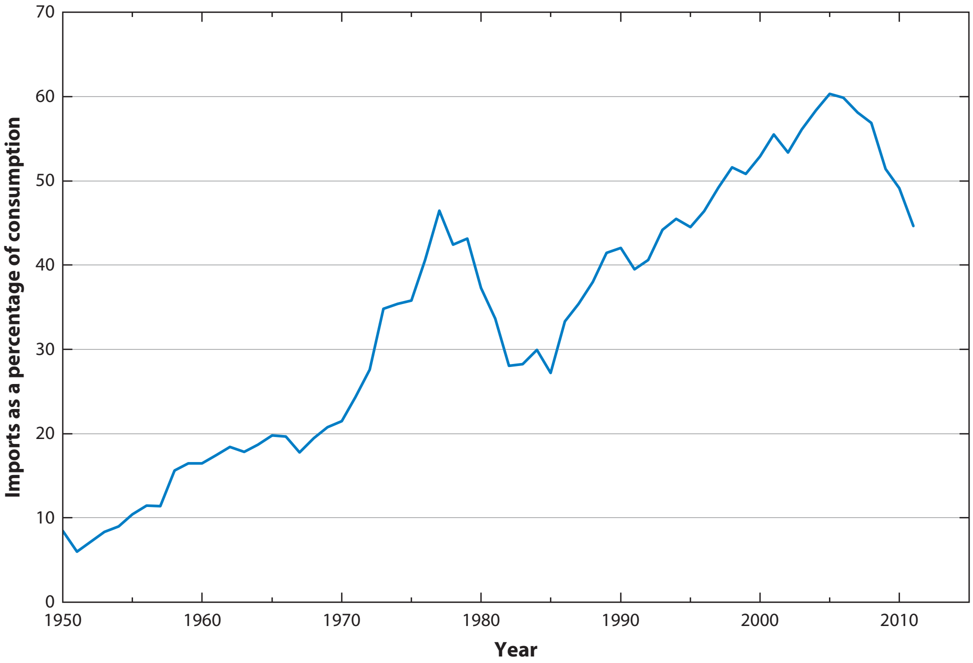

Figure 5

US oil imports as a percentage of oil consumption, 1950–2010. Data for net petroleum imports and total petroleum consumption are from EIA *Annual Energy Review*, table 5.1a (**http://www.eia.gov/totalenergy/data/annual/index.cfm**).

empirical matter. Adelman (1980) argues that OPEC does not function with sufficient effectiveness to offset monopsony behavior with any precision. Alhajji & Huettner (2000) find evidence of Saudi Arabia serving as a dominant producer in the 1973–1994 period but do not find evidence of cartel behavior by OPEC.

Perhaps more to the point, monopsony behavior is not related to the notion of energy security as defined in this article. Any policy that reduces consumption of an energy source, here oil, enhances the ability of US households, businesses, and government to accommodate disruptions of supply in energy markets. But the transfer of rents, the goal of the exercise of monopsony power, does not enhance our ability to accommodate supply disruptions.

2.3. Responsiveness to Market Shocks

The policy focus on energy security stems from society's inability to find ready substitutes for energy in the production of goods and services valued by consumers. More precisely, the elasticity of demand for energy is low. Combined with a low short-run price elasticity of supply, small fluctuations in supply and demand can have large price impacts. Consider the summer of 2008, when oil prices spiked to an all-time high of more than $145 per barrel [see July 3 West Texas Intermediate (WTI) crude price data from US Energy Information Administration 2013a]. This price represented a nearly 50% increase in price over the previous 6 months and sparked considerable policy discussion about the possible role of speculators in driving up oil prices. Simple demand and supply theory may help explain the price spike. A supply shortfall (in percentage terms) of Δ would require a percentage price increase of δ to equilibrate supply and demand, where

$$\delta = \frac{\Delta}{\varepsilon_S - \varepsilon_D}, \tag{5}$$

ε_S is the price elasticity of supply, and ε_D is the price elasticity of demand. The short-run elasticities of supply and demand for oil are on the order of 0.05 and −0.05, respectively (see survey in Smith 2009). On the basis of these elasticity estimates, a 5% shortfall in supply (roughly 4 million barrels per day in 2008) would require a 50% price increase to reduce demand and increase supply sufficiently to clear the market. Smith (2009) documents a number of supply shocks in early 2008 that quickly get us in the neighborhood of 4 million barrels a day of reduced supply. Oil speculation may or may not be an issue in contributing to price volatility, but very small short-run supply and demand elasticities can contribute to very large short-run price changes in response to modest supply curtailments.

The ability of households, businesses, and government to react to disruptions in supply varies significantly across fuels. Petroleum accounted for 93% of transportation fuels in the United States in 2012, highlighting the limited substitutability of other fuels for oil in this sector.[8] Although electric vehicles are making inroads into the transport sector, they will not play a significant role in the short run in a shift away from petroleum toward electricity (from natural gas, coal, or other sources). In contrast, coal and natural gas accounted for 41% and 24% of electricity production, respectively, in 2012. Flexibility in dispatch along with new generating capacity means that the elasticity of substitution between natural gas and coal is much higher in electricity production than that between oil and any other fuel in the transport sector. As a result, households and businesses are less susceptible to supply disruptions, given the opportunities for fuel substitution in the near term.[9] Even in the absence of fuel substitution, fuel-sensitive sectors can hedge price risk through markets. According to a survey undertaken by Mercatus Energy Advisors (2012) in the winter of 2011–2012, more than 80% of airlines hedge against fuel costs in some form, although their degree of hedging varies. The median share of fuel costs hedged was less than 40% in the survey, with slightly more than 20% of firms hedging more than three-fifths of their fuel costs. Whether airlines are hedging the appropriate amount of risk or hedging with the optimal set of instruments is not clear. But the existence of private risk mitigation options suggests the potential for moral hazard problems in the presence of government policy to reduce energy price risk.

The vulnerability to fuel disruptions varies across countries for given fuels. Slightly more than 20% of electricity produced in the United States came from nuclear power in 2012. Short-term disruptions to nuclear electricity production can be quickly replaced by other sources in the United States. The Congressional Budget Office (2012) notes that the August 2011 earthquake in the eastern United States caused two nuclear power plants to shut down temporarily. Although power prices spiked by more than 50% in the short run, costs fell back to pre-earthquake levels very quickly (Congressional Budget Office 2012, p. 13). This situation contrasts with the situation in Japan following the Fukushima accident. Prior to the March 2011 tsunami that ultimately destroyed units 1–4 of the Fukushima Daiichi nuclear complex, Japan was generating some 30% of its electricity from nuclear power, with plans to raise that percentage to 40% by 2017 [information taken from World Nuclear Association

[8]Data in this section are taken from Energy Information Administration (2013b).

[9]This statement is true in general. But local bottlenecks may need attention. Despite the wide availability of natural gas, some sections of the country may face energy supply vulnerabilities due to specific circumstances. For example, two major pipelines bring natural gas into the New England region. These pipelines operate at near capacity, and electricity-generating plants have a lower level of priority to gas than do households and businesses. Thus, New England is vulnerable to natural gas–related electricity shortages in periods of extreme cold. The independent system operator for New England (ISO-NE) has identified this vulnerability as one of three significant challenges facing the system (ISO New England 2013).

website (**http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan/**), accessed July 2013]. Instead, following the accident, Japan has gradually shut down all its nuclear power plants, and the process of restarting them is uncertain and subject to considerable regulatory and political delay. Japan has scrambled to replace the lost electricity and has increased its imports of liquefied natural gas (LNG) and oil for electricity generation. Natural gas imports rose by 11% and oil imports rose by 2% after the accident. The natural gas imports cost nearly $70 billion—double the cost of imports in the previous year—and contributed to the largest trade deficit in Japan's history (Nakano 2013). Meanwhile, stringent energy conservation programs were put into effect, and Japan reduced its electricity consumption by 12% and reduced peak demand by 18% in the summer of 2011 (relative to 2010). See Hayashi & Hughes (2013) for an analysis of policy responses in Japan to the disaster.

3. NONECONOMIC ENERGY SECURITY CONSIDERATIONS

3.1. Supply Security

Above I argue that the share of imported oil in domestic consumption is unrelated to the vulnerability of US consumers to oil price shocks. That is not to say, however, that the security of supply is an unimportant concern. Although oil prices may adjust nearly instantaneously to a shortfall in supply somewhere in the world, the ability of any single country to balance supply and demand throughout the system may be difficult. The United States, for example, imported 10.5 million barrels of petroleum products a day in 2012 (see BP 2013). More than half of the imports came from Canada (28%) and Latin America (28%). Disruptions in oil supply from Canada, for example, could put pressure on suppliers to meet demand at refineries in the upper Midwest.

The limited ability to respond to supply-demand imbalances in the US market is reflected to some extent by the price spread between Brent oil and WTI oil. Historically, WTI oil has traded roughly on par with Brent oil. Starting in 2011, Brent oil began to trade at a significant premium, peaking at nearly $30 a barrel in September 2011 (a premium of 30–35% over the WTI spot price). The spread was caused in part by an inability to move oil from Cushing, Oklahoma, where WTI is priced, to Gulf of Mexico refineries or refineries in other parts of the country. A combination of pipeline capacity expansions, reversal of flow in a key pipeline from West Texas oil fields to the Gulf of Mexico, and increased use of rail to move oil has reduced the spread (Pan 2013).

Whether price fluctuations due to regional supply demand imbalances constitute a significant security problem is not clear. One could reasonably view the price differentials as important market signals to spur needed investment in pipeline capacity and other capital to re-equilibrate the market.

3.2. Energy Infrastructure

Energy-related capital constitutes a significant share of nonresidential fixed assets. **Table 2** reports the net stock of energy-related nonresidential fixed assets in 2012.

Nonresidential energy fixed assets were valued at $4 trillion in 2012. This number represents 12.5% of total nonresidential fixed assets and is composed primarily of structures (electric generating and mining).[10] Although not the focus of most economic analyses of energy security, security of energy capital is a significant concern for policy makers and private firms. Presidential Policy Directive 21, issued in 2013, designates 16 critical infrastructure sectors, of which energy is one

[10]The share of private nonresidential energy fixed assets in total private nonresidential fixed assets is 18.5%. These estimates do not include the value of power equipment in the US military, transportation-related assets, or residential energy–related capital and durable goods. Nonresidential transportation equipment and residential motor vehicle durable goods add $2.46 trillion to the figure in **Table 2**.

Table 2 Current cost net stock of nonresidential energy fixed assets, 2012

Category	Billion $ (2012 values)	
Equipment and software		691.5
Engines and turbines	108.9	
Electrical transmission, distribution, and industrial apparatus	459.3	
Mining and oil field machinery	97.2	
Electrical equipment, not elsewhere classified	26.1	
Structures		3,311.4
Power	1,671.5	
Mining exploration, shafts, and wells	1,322.8	
Federal power	14.1	
State and local power	303.0	
Total		**4,002.9**

From BEA (2013), fixed-asset-account tables 2.1, 4.1, 7.1B.

(Office of the President 2013).[11] The focus of the directive is to "strengthen the security and resilience of its critical infrastructure against both physical and cyber threats" (Office of the President 2013, p. 2). In developing an energy sector–specific plan, the Departments of Homeland Security and Energy focus on ensuring a "robust, resilient energy infrastructure in which continuity of business and services is maintained" (Departments of Homeland Security and Energy 2010, p. 1). The plan focuses on information sharing across government agencies and the private sector, physical and cyber security, coordination and planning, and strengthening of public confidence.

The National Research Council (2009) report considers to what extent US energy infrastructure was vulnerable to accidents and terrorist attacks, focusing particularly on LNG facilities, oil spills from ships, oil and gas pipelines, and nuclear power plants. Citing Parfomak & Vann (2009), the study concludes that the risk of incidents was quite small. The focus on LNG facilities came at a time when dramatic growth in the number of LNG regasification facilities was expected. The boom in shale gas production in the United States has led to a marked shift away from import toward export facilities, and the Federal Energy Regulatory Commission (FERC) is currently considering a number of applications either to build new export facilities or to convert import facilities to export facilities.[12]

The National Research Council (2009) focus on spills from ships and oil and gas pipelines follows from the study's focus on externalities associated with energy production and consumption. Little, if any, concern is focused on energy security issues. Security issues are viewed as significant by policy makers in the operation of nuclear power plants. Holt & Andrews (2012) recount industry requirements set forth in the Energy Policy Act of 2005 (P.L. 109-58) for more extreme design basis threats that a nuclear power plant must be able to repel. Plants are required to

[11]Presidential Policy Directive 21 is an update to the original critical infrastructure presidential directive, which President George W. Bush issued in 2003 (Office of the President 2003).

[12]According to FERC, 3 import facilities have been proposed and 13 export facilities have been proposed to FERC. There are currently no operating export terminals in the United States. See FERC website at **https://www.ferc.gov/industries/gas/indus-act/lng.asp**.

conduct mock attack exercises at least once every 3 years. According to Holt & Andrews, 136 mock attacks had been carried out by the end of 2010, with 10 resulting in the simulated destruction of the nuclear facility. The Nuclear Regulatory Commission (NRC) responded with enhanced security requirements for all nuclear facilities.

In addition to possible terrorist attacks, the NRC ordered all nuclear power plants to develop security plans to address damages that could result from an aircraft crashing accidentally or deliberately into the facility. The storage of spent fuel at existing nuclear power plants is another area of concern for the NRC, given the failure to establish a national repository for spent nuclear fuel.

Cybersecurity is increasingly a concern for nuclear power plants and other energy infrastructure, especially after the release of the Stuxnet virus caused significant damage to the Iranian nuclear program in 2010 and raised concerns about state-sponsored cyberattacks on energy and other critical infrastructure. The Department of Homeland Security's Industrial Control Systems Cyber Emergency Response Team flagged 198 cyber incidents in 2012, with the energy sector facing the largest share (41%) (Department of Homeland Security 2012). The NRC released cybersecurity regulations and a subsequent regulatory guide for the program (Nuclear Regulatory Commission 2009). Little economic analysis has been undertaken on the issue of cybersecurity. Kobayashi (2005) argues that much of the research and information on cybersecurity has the character of public goods and is thus underprovided by the private sector compared with the socially optimal level of cybersecurity-related research and information.

Conceptually, energy infrastructure is no different from any other form of infrastructure that is vulnerable to attack by terrorists or countries with which the United States is in conflict. For any type of critical infrastructure, the important question is how resilient the system is to attack. One aspect of resilience is the ability of the system to work around damaged or destroyed infrastructure. If the Holland Tunnel from New Jersey to New York City were unexpectedly closed, considerable disruption would ensue. But some vehicles would adapt by shifting to other bridges and tunnels out of Manhattan while other commuters would substitute into trains, ferries, and other modes of transportation. Damage to oil or natural gas infrastructure would elicit a similar response. Electrical grids, in contrast, may not have the same degree of resilience. Electricity differs from other commodities in the need for supply to be balanced by demand at all points throughout the system at all times. Failure to balance supply and demand can lead to grid failures. For this reason, grid operators require redundancy in the system to anticipate potential failures, accidental or otherwise.

This sensitivity of electrical transmission and distribution systems to failures that can cascade was dramatically made clear in August 2003, when tree branches in Ohio brought down a power line, only to have the resultant power surge bring down transmission systems from the Midwest through the Northeast. Ultimately, 50 million people lost power at an estimated cost of nearly $10 billion, according to DiSavino (2013).[13] DiSavino notes that a combination of stronger mandatory standards, fines, training, and improved equipment has reduced the risks of such a large blackout. But the electrical transmission and distribution system remains perhaps the most fragile energy infrastructure.

3.3. Energy and National Security

US reliance on oil contributes to high oil prices that support a number of unstable governments as well as governments with interests at odds with those of the United States. This fact has long been

[13]Anderson & Geckil (2003) estimate an economic loss of $6.4 billion, with most of that due to lost wages and profits. Using an input-output model, Anderson et al. (2007) estimate a similar cost impact.

recognized (cf. Deutch & Schlesinger 2006). The implications for national security are less clear-cut. Reducing oil consumption (as opposed to oil imports) may lessen the influence of oil rich countries. But it may not materially affect military and strategic thinking. As the National Research Council (2009) report notes, our presence in the Middle East not only safeguards oil transport routes and oil-producing regimes but also contributes to political goals such as fighting terrorism and providing support for Israel. Noting the work of Bohi & Toman (1993), the report concludes that the marginal cost of oil-related military spending is essentially zero. In other words, a marginal (or even inframarginal) reduction in oil consumption may not affect our national security planning or spending significantly.

To be clear, energy is an integral part of military readiness and a critical military input. One of the lessons from the wars in Iraq and Afghanistan is the importance of fuel conservation given the logistical difficulties of maintaining supply lines. But this is simply a military logistical issue similar to the countless other logistical supply concerns that the military grapples with on a daily basis.

3.4. Energy and Foreign Policy

The National Research Council (2009) report identifies a number of channels through which domestic energy consumption affects foreign policy. First, oil revenues support regimes, many of which (viz. Iran and Venezuela) have foreign policies at variance with those of the United States. States may also eschew economic assistance tied to reforms designed to promote greater political and economic openness. Such a reluctance to accept conditional aid may create difficulties for the United States internationally but is not, as the report notes, an externality associated with energy consumption. Second, the report points out that US oil consumption may constrain foreign policy, citing a 2006 report by the Council on Foreign Relations that notes that oil dependence can induce political realignments that constrain the ability of the United States to form partnerships to achieve common objectives. Perhaps the most pervasive effect arises as countries dependent on imports subtly modify their policies to be more congenial to suppliers. For example, China is aligning its relationships in the Middle East (e.g., Iran and Saudi Arabia) and Africa (e.g., Nigeria and Sudan) because of its desire to secure oil supplies (Deutch & Schlesinger 2006, pp. 26–27). More recently, the heavy dependence of many European countries on Russian natural gas has complicated efforts by the United States to develop a strong sanctions response to Russia's annexation of Crimea and undermining of Ukrainian control over the eastern part of its country (see, for example, Ratner et al. 2013 and Kennedy 2014). As a related matter, Russia may have acted more aggressively toward Ukraine, recognizing that European dependence on Russian natural gas would mute any reaction to Russian military actions in the Ukraine.

These are important political issues that have been studied more by political scientists than economists. Moreover, these foreign policy–related issues are high on policy maker radar screens and may drive much of the energy security policy discussion to the detriment of the economic issues associated with energy security. An important area of future research is to assess whether and how economic costs associated with energy market–induced constraints on foreign policy can be measured and analyzed and so provide greater balance in policy discussions around the topic of energy security.

4. ENERGY SECURITY POLICY INSTRUMENTS

Energy security is often invoked as a rationale for a number of policy measures. Most sensible policies focus on reducing the risk of disruptions in supply and the impacts of supply disruptions. Measures that contribute to increasing the elasticity of supply and demand for energy are also useful, as they reduce the price volatility associated with shifts in demand and supply.

4.1. Policies to Reduce Energy Intensity

The United States has made dramatic improvements in the efficiency with which it uses energy. Energy intensity, as noted above, has been cut roughly in half since 1973. Many energy efficiency policy proposals have positive net present value, especially when one accounts for local and global externalities associated with the use of fossil fuels. Gillingham et al. (2009) catalog a list of potential market and behavioral failures that would justify energy efficiency policies. Broadly speaking, the market failures include environmental externalities and lack of marginal cost pricing for electricity, capital market constraints, innovation spillovers in efficiency innovation, and insufficient and asymmetric information. The authors note that the literature is not settled on the extent of market failures or on the most appropriate policies to address the most significant of the hurdles to efficient energy efficiency investments. Pricing externalities or regulating emissions raises the price of energy and directly stimulates energy efficiency investments. Public funding for research and development (R&D) is likely to counteract socially suboptimal investments in R&D. But this result is true of R&D in general and is not limited to energy-related innovations. Moreover, the share of social—as opposed to private—benefits of R&D in total benefits falls as we move downstream from pure research to technology innovation to deployment. Public policy often focuses more on downstream research, development, and deployment in which private benefits are most easily captured by firms. In addition, directed R&D runs the risk of picking technologies that ultimately do not have the highest return on investment. Focusing on supporting pure research across the board is likely to result in support of research with the greatest potential for positive spillovers.

4.2. Policies to Encourage Energy Diversity

Diversity in the fuels consumed provides benefits in the form of dampened impacts of supply shocks on prices and economic activity. If the share of petroleum in the mix of energy sources is reduced, any oil-related supply reduction will have a smaller impact on the economy. Although an increase in oil prices will presumably also lead to an increase in the price for substitutes to oil (depending on the elasticities of substitution between oil and other energy sources), the overall energy price increase will be lower with a lower share of oil in the energy mix.

The relationship between fuel diversification and security is not entirely straightforward, however. McPhail & Babcock (2012) argue that US ethanol policies have reduced the price elasticity of gasoline and so have increased the volatility of gasoline prices in response to supply shocks. Such policies, interestingly, have also increased the volatility of corn prices in response to supply shocks in the corn market.

Diversity in supply sourcing is often cited as an energy security issue. The economic security benefits of diversification on this dimension are less clear-cut. To the extent that energy sources trade in world markets, supply shortfalls from one supplier can be made up by purchases from other suppliers. Increasing the number of potential energy suppliers overall has benefits in reducing market power among suppliers. But it is not clear that increasing the number of supply sources for an individual country is especially beneficial.

4.3. Infrastructure Investment

Adequate infrastructure is critical to the reliability of energy supply. New England, for example, has seen a surge in the planning and construction of natural gas–fired electricity-generating units at a time when existing pipelines to bring natural gas into the region are near capacity and raise concerns about potential supply shortfalls (ISO New England 2013). High-voltage electricity transmission lines are also needed to match the growth in supply of new generating sources and, more critically, to handle the increased amounts of variable load from wind and other variable sources. There was recently considerable concern over obstacles to new investments in cross-state high-voltage transmission, the type of capital needed to move wind power from high-wind, low-density regions to urban areas where electricity demand is high (Metcalf 2010a). High-voltage transmission construction has picked up since the 2004–2008 period, with the number of miles of ≥200-kV lines added more than doubling between the 2004–2008 period and the 2008–2012 period (North American Electric Reliability Council 2012, p. 37). The government's role in promoting infrastructure investment is more in the area of planning and coordination than in financing investment.[14]

4.4. Stockpiling

After the 1973–1974 oil embargo, Congress created the Strategic Petroleum Reserve (SPR), designed to contain sufficient oil to cover 90 days of net imports (Andrews & Pirog 2012). Congress authorized the physical storage of 750 million barrels in 1978 and expanded capacity to 1 billion barrels in 2005, although current capacity is limited to 727 million barrels. Currently, the SPR contains slightly less than 695 million barrels (Energy Information Administration 2013b). SPR drawdowns are authorized upon a presidential finding that a "severe energy supply interruption" exists or is imminent (Andrews & Pirog 2012, p. 3). SPR releases have been authorized in the face of international political crises (e.g., the 1990 invasion of Kuwait by Iraq and the subsequent Desert Storm response, the 2011 Libyan supply shortfalls due to civil war) as well as domestic weather-related supply curtailments (e.g., Hurricane Katrina in 2005). In addition, 23 million barrels were sold in 1996 to finance deficit reduction in the Clinton administration. The deficit reduction sale was controversial, and Obama administration proposals for SPR oil sales to reduce the deficit have not been taken up by Congress (Andrews & Pirog 2012).

The SPR is controversial on several levels. First, there are concerns that presidents may try to use SPR additions and withdrawals in an effort to manipulate oil prices. Second, whether the existence of the SPR appreciably affects world oil prices is unclear. Any drawdown large enough to affect world prices would dramatically deplete reserves and could be offset by producer supply curtailments (Considine 2006). Other issues include the rate at which oil can be withdrawn from the SPR stocks and the concentration of reserves in one part of the country (the Gulf of Mexico area). Finally, there have been concerns that the type of oil stored in the SPR is not consistent with the types of crude that refineries are currently designed to process (Andrews & Pirog 2012).

4.5. International Coordination

The International Energy Agency (IEA) was established in the aftermath of the 1973–1974 oil crisis in part to coordinate energy supply and demand activities among OECD countries. One of the IEA's activities is to coordinate strategic petroleum reserve management. The IEA, for example, requires members to stockpile oil to cover at least 90 days of net imports and to maintain measures to coordinate with other IEA members in the face of oil supply disruptions. The IEA, for example, coordinated the 2011 release of oil during the Libyan civil war. Although China, India, and other

[14]The federal government does support transmission and other infrastructure investments through accelerated tax depreciation. The tax treatment of electricity transmission lines, however, is significantly less generous than the treatment of other energy assets (see Metcalf 2010b).

major developing countries are not part of the OECD and are therefore not eligible for membership in the IEA, the IEA increasingly works closely with many of these countries to coordinate supply and demand issues.

4.6. Taxes and Subsidies

Taxes can be used to raise the price of energy and so would discourage consumption, thereby contributing to a lower energy intensity in the economy. Higher taxes in the short run affect consumer behavior directly by encouraging less use and in the long run contribute to a more energy efficient capital stock. The difference in vehicle fuel efficiency between the United States and Europe is due to a number of factors, but the higher gasoline and diesel prices in Europe are certainly an important factor. Subsidies on new energy sources (e.g., wind and solar) would also contribute to a more diversified energy supply system. Finally, removing subsidies on fossil fuel production in the United States would raise the price of energy and so discourage energy use. Metcalf (2007) notes, however, that removing all tax incentives for fossil fuel production in the United States would be unlikely to raise oil prices by more than approximately 0.4%. A carbon tax would also discourage energy consumption but would dampen coal consumption substantially more than oil and natural gas consumption. Although such a tax would have significant environmental benefits (in terms of both local air pollution and greenhouse gas emissions), it would be unlikely to have significant energy security benefits unless the tax were sufficiently high to shift us from a petroleum- and fossil fuel–based economy to a non–fossil fuel economy. Without a clear understanding of what the energy mix would be in this new world, conjecturing the energy security implications of this shift is difficult.

5. CONCLUSION

Energy security is the ability of US households, businesses, and government to accommodate disruptions of supply in energy markets. The literature on the economics of energy security is thin and has focused in large measure on measuring the externalities associated with energy security. That focus is misplaced, in my view. The real energy security issues may be more micro in nature. The scope includes issues such as the costs of bottlenecks in specific locations (e.g., Japan following the Fukushima nuclear power accident and natural gas in supply bottlenecks in New England).

Future research on this topic might well benefit from considering the following questions. First, what are the network spillovers from private investments in electricity transmission lines, and to what extent are they captured by investors? Theoretical analysis of private investment in transmission indicates a number of possible market failures (see Joskow & Tirole 2005), but there is little empirical analysis. Second, what are the economic costs of electricity supply disruptions? Although there has been extensive work on the macroeconomic costs of oil price shocks (e.g., Kilian 2008, 2009; Hamilton 2009), analysis of major and minor electricity blackouts is less extensive.[15]

Third, how can we reconcile differences in attitudes toward energy security between economists and policy makers? This may be the most important question of all. Once one goes beyond the literature on energy security externalities discussed above, there is little focus by economists on this topic. Meanwhile, it has been a serious focus of policy makers since the 1973 Arab oil embargo

[15]Recent work includes Alam (2013), Alcott et al. (2014), Fisher-Vanden et al. (2012), and Leahy et al. (2012) in addition to Anderson et al. (2007).

(if not earlier). One possible explanation is that some of the energy security concerns relate to unquantifiable spillovers into areas such as foreign policy. Here political scientists and scholars in international studies may find institutional and qualitative analysis more useful. But their work may be helpfully augmented by more economic analysis than is currently taking place.

Moreover, policy concerns may be more about policy coordination and planning, which although important are not natural areas of study for economists. In addition, concerns about ensuring the safety of energy supply chains are more the domain of military logistics and security than that of economics. But there may also be unexplored areas for economists to develop new research programs.

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