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**NAVAL
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MONTEREY, CALIFORNIA

THESIS

**ENDING AMERICA'S ENERGY INSECURITY:
HOW ELECTRIC VEHICLES CAN DRIVE THE
SOLUTION TO ENERGY INDEPENDENCE**

by

Fredrick Stein

December 2011

Thesis Advisor:

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**ENDING AMERICA'S ENERGY INSECURITY HOW ELECTRIC VEHICLES
CAN DRIVE THE SOLUTION TO ENERGY INDEPENDENCE**

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Submitted in partial fulfillment of the
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**MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)**

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ABSTRACT

The homeland/national security threat posed by the United States' dependence on foreign oil has been part of the American discourse for years; yet nothing has been done. No pragmatic, realistic step-by-step plan has been pursued to end this scourge on the American people. The solution can be found in the problem. Net imports of oil account for approximately 50 percent of the oil the U.S. consumes. Likewise, 50 percent of oil consumed in the U.S. is consumed as motor gasoline. If overnight the U.S. stopped using oil to power its vehicles, if overnight drivers switched to electric vehicles, then overnight the U.S. would become energy independent. Using historical data to establish the effect of gasoline price changes on consumer vehicle choice, a predictive model has been created showing the expected switch to electric vehicles if the price of gasoline increases and the cost of electric vehicles decreases. There is a cost to energy independence: two to five dollars per gallon of retail gasoline sold. If monies raised from the tax are used to lower the price of electric vehicles, build recharge infrastructure, and dampen the regressive nature of the tax, energy independence is a few short years away.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASCM	Anti-Ship Cruise Missile
CBO	Congressional Budget Office
CAFE	Corporate Average Fuel Economy
DOE	United States Department of Energy
EV	Electric Vehicle
EIA	United States Energy Information Administration
FTC	Federal Trade Commission
IAFC	International Association of Fire Chiefs
MSRP	Manufacturer's Suggested Retail Price
PHEV	Plug-in Hybrid Electric Vehicle
TEPCO	Tokyo Electric Power Company

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I. INTRODUCTION

A. PROBLEM STATEMENT

Dependence on foreign oil presents a growing threat to U.S. national and homeland security. This threat manifests itself in several ways: it places unhealthy restraints on U.S. and allied nations' policy choices; it weakens the nation economically by adding to the trade deficit; it forces our military to protect vital oil trade routes; and it strengthens our adversaries by providing funding for their activities. Given that the amount of oil imported by the country is roughly equal to the amount of oil used in the U.S. to power automobile transportation, a shift to alternative transportation technologies could dramatically improve our national and homeland security. Electric vehicles (EVs) provide the most promising path toward ending our dependence on foreign oil.

For purposes of this thesis, "dependence on foreign oil" is the situation where the domestic demand for oil exceeds the available domestic supply. When the domestic supply is insufficient, some domestic consumption of oil must be satisfied by sources that originate in locations other than the states, territories and possessions of the United States. With this definition in mind, net importation of oil is more relevant than total importation numbers though much of the literature relies on total importation data.

1. The Scope and Ramifications of Dependence on Foreign Oil

In 1973/1974, the U.S. imported approximately 28 percent of the oil that it consumed (U.S. Energy Information Administration [EIA], 1998). At only 28 percent, the six-month long 1973/1974 oil embargo caused gas prices to triple and long lines at gas stations (Leotta, 2006, p. 4). Today, the United States imports approximately 50 percent of the oil that it consumes (EIA, 2011d). Imagine what would happen should a similar disruption occur, now that the degree of dependence on foreign oil has markedly increased.

The economic cost of dependence on foreign oil is staggering. The United States has an oil trade deficit of approximately \$1,000,000,000 per day, larger than our trade deficit with China (Powers, 2010), which in 2010 was approximately \$748,000,000 per

day (U. S. Census, 2011). Oil consumption represents 40 percent of America’s energy needs, with 20 percent of the oil the U.S. consumes coming from the Persian Gulf Region (Cohen, 2007). The cost to the United States is compounded. Not only do we send one billion dollars out of our economy every day, but much of that same money is then used in a manner that directly threatens our security. Time and again, the U.S. military and national security leaders have warned of the substantial risk this outflow of capital poses to the security of the United States. For example, Vice Admiral Dennis McGinn has cautioned that the oil trade deficit, much of it enriching nations that wish us harm, is an unsustainable transfer of wealth that has us literally funding both sides of the conflict in the “war on terror” (Powers, 2010). Former national security adviser Robert McFarlane and former CIA director R. James Woolsey, have recently described our dependence on foreign oil as, “the well from which our enemies draw their political strength and financial power: the strategic importance of oil, which provides the wherewithal for a generational war against us” (McFarlane, 2011). When asked about the most important area of research for aiding those under his command, Marine General James Mattis responded by imploring that the country, “Unleash us from the tether of fuel” (Powers, 2010). Similarly, a panel of 11 former generals and admirals testified that “dependence on foreign oil leaves us more vulnerable to hostile regimes and terrorists” (Powers, 2010).

The restraints from oil dependence on U.S. foreign policy decisions are untenable. For example, as the nation struggles to blunt Iran’s drive towards nuclear weapons, administration officials are wary of enacting sanctions on Iranian oil exports. They fear that it might drive up oil prices when the United States and European economies are weak. As they consider the probable impacts, they are forced to conclude that in the end, they simply cannot predict what would happen (Sanger, 2011).

2. A Path to Independence

Energy dependence is a product of the United States’ importation of oil. Though the U.S. is the third largest producer of oil in the world (EIA, 2010b; EIA, 2011d), it still imports roughly 60 percent of the total oil it consumes (Brooker, 2010). Since the U.S.

also exports approximately two million barrels of oil per day, net imports are approximately 50 percent of U.S. consumption (EIA, 2010a, p. 128). Roughly two-thirds of the oil used in the United States is for transportation (Etezadi-Amoli, 2010). Virtually none of the oil consumed (approximately 0.2 percent in 2009) in the United States is used for electricity production (EIA, 2010a, p. 152). That means that adding nuclear or clean coal facilities, building wind farms, installing solar panel fields, etc., do little to foster energy independence. Those technologies may replace fossil fuel combustion for the generation of electricity but not in a manner that can currently be utilized by most of the transportation sector that depends almost exclusively on the combustion of oil.

Electric vehicles can change all that. They provide a path for eliminating our dependence on foreign oil. There is a close, though not perfect, equivalence between the amount of net imported oil, and the amount of oil used for motor gasoline. Of the 18.7 million barrels of oil consumed per day in the U.S., approximately nine million barrels are used as motor gasoline (EIA, 2010a, p. 148). Motor gasoline is by far the single greatest use of oil (see Figure 1). Replacing the other uses of oil would require a half dozen or more other changes, some of which are not yet technically feasible. EVs shift the energy required for automobile transportation to the electric power sector, and, as long as that electric power is generated using domestically available sources of energy other than oil, the U.S. would reduce its overall consumption of oil by roughly 50 percent. This establishes that if the United States were to cease using oil to power automobiles, it would effectively eliminate its dependence on foreign oil.

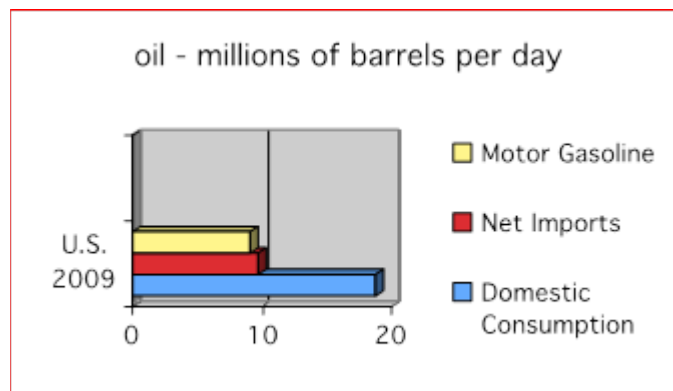


Figure 1. Oil Imports, Consumption and Amounts Used for Motor Gasoline (After EIA, 2010a, pp. 128, 148)

There is analysis of recent historical fluctuations in gasoline prices that looks beyond simple supply and demand. It shows that with long-term price increases in the cost of gasoline, people will reduce their consumption of gasoline, at least partially, by moving to more fuel-efficient vehicles (Congressional, 2008).

EVs provide the best means of eliminating the use of petroleum products to power automobiles in the United States. By moving to EVs (provided the increased electricity demands are not met through the use of petroleum), the yellow bar in Figure 1 can be eliminated, ending the need for the oil represented by the red bar, net imports of oil. It is important to note, however, that this transformation will require upgrades to and expansion of the nation's electric power infrastructure, thereby requiring infrastructure investments. More details on that issue are discussed in Chapter V.

Although the move to EVs is likely to occur slowly in response to market forces alone (Hensley, 2009), given the urgency of the security threat posed by dependence on foreign oil, there is a dearth of policy designed to increase the pace of transformation to an EV fleet. While there are many discussions of the effect of EVs on the environment, there are no policies that look to speed up this transformation from a national or homeland security perspective. Speeding up EV adoption depends on several factors, including: improving battery efficiencies and capacities to increase range; bringing the total cost of EV ownership in line with or below the total cost of gasoline powered vehicles; increasing the pace of EV infrastructure development (e.g., recharge/refuel facilities); and increasing consumer adoption of EVs (Hensley, 2009).

B. RESEARCH QUESTIONS

1. Primary Question

How can various policy choices affect consumer adoption of electric vehicles to move the United States from internal combustion vehicles to electric vehicles?

2. Secondary Questions

1. Which policy choices would lower the demand for gasoline powered automobiles?

2. Which policy choices would raise demand for electric vehicles? Although this question is related to secondary question 1, there may well be policies that lower the demand for internal combustion vehicles without specifically increasing the demand for EVs.
3. What are the potential unintended consequences of policy choices favoring electric vehicle adoption?

C. SIGNIFICANCE OF RESEARCH

This thesis will fill the void in the literature looking at EV adoption as a national/homeland security concern. There is ample analysis of EV adoption from an environmental and purely economic perspective, but there seems to be no literature that gives serious consideration to adopting EVs as a potential solution to the security vulnerability created by energy dependence. Additionally, there does not appear to be a comprehensive look at how various policy choices might be used specifically to bring about the speedy adoption of EVs. This thesis will assimilate the available literature and data to establish (1) that EVs have the potential to solve the security vulnerability inherent in energy dependence and, (2) what policies can be implemented to bring about the speedier adoption of EVs in the United States.

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II. LITERATURE REVIEW

Oil is often the topic of public debate, political discourse and academic research. A great deal of time and resources are spent discussing the sources of oil, the environmental and geopolitical effects of oil and dependence on foreign sources for oil and how the nation might reduce its use of oil/foreign oil. There is also literature discussing the national/homeland security implications of energy dependence; however, there is an absence of literature either discussing how EV adoption might solve that security threat or describing what policy choices can be used to speed up EV adoption.

A. DEPENDENCE ON FOREIGN SUPPLIES OF OIL AS NATIONAL SECURITY/ HOMELAND SECURITY ISSUE

1. Direct Threats to the Supply of Foreign Oil

There is ample material establishing the existence of the security threat posed by dependence upon foreign sources of oil. At the surface, rhetorical level, there exists a robust record of high visibility proclamations that energy dependence is a critical security issue for the United States (for example, see CNN, 2010). Additionally, for decades the nation's leaders have recognized the security importance of energy independence, espousing its centrality to national security. Video clips of every U.S. president from Richard Nixon to the current President capture each of them discussing the importance of ending the United States' dependence on foreign oil (Stewart, 2010). There is also ample media coverage of the rhetoric of nations hostile towards the U.S. describing how they are willing to cut off the United States' supply of oil. This is primarily centered on oil producing countries from the Middle East and Venezuela. This literature tends to be sound bites without much meat, but the advantage is that it is designed for public consumption, helping to socialize the idea of energy dependence. President Obama recently announced that for "geopolitical and economic reasons," the nation needed to reduce its reliance on imported oil by about 30 percent over the next 10 years (Broder, 2011).

A more in depth body of literature examining energy dependence also exists. The 1973/1974 oil embargo provides historical precedence for foreign nations using oil as a lever to affect U.S. national policy (Paust, 1974). In 1973/1974, the U.S. imported approximately 28 percent of the oil that it consumed (EIA, 1998). The embargo, sometimes referred to as “Energy Pearl Harbor Day” (Light, 1976), was sufficiently severe to serve as the catalyst for legislative action concerning the use of fuel. Gas shortages were significant enough that, along with a tripling of world oil prices, gasoline consumption in the U.S. actually decreased by 2 percent in response to the embargo (Leotta, 2006, p. 4). The situation was so severe that naval oil reserves were tapped for emergency civilian supplies (Light, 1976).

Literature has addressed the present threat from state actors. Hugo Chavez, president of Venezuela, has threatened to cut the supply of oil to the U.S., not because of the threat of a U.S. invasion, but as leverage to prevent Colombia from invading Venezuela (CNN, 2010). Similarly, Russia has shown it may be willing to take military action to control the supply of oil flowing to the West. The invasion of Georgia may have been more about the Baku-Tbilisi-Ceyhan pipeline (a conduit of oil to the West owned by U.S. and British energy firms) than about support of the separatists in South Ossetia (Kimery, 2008).

Similar threats have come from non-state actors like Osama bin Laden and Ayman al-Zawahiri, who have called for attacks on economic assets, especially energy sources (Cohen, 2007). In a tape aired by Al-Jazeera in February 2006, Zawahiri said, “I call on the mujahedeen to concentrate their attacks on Muslims’ stolen oil, most of the revenues of which go to the enemies of Islam while most of what they leave is seized by the thieves who rule our countries” (Cohen, 2007). The non-state threats are broader than just Al Qaeda with groups specifically attempting to wreak havoc in international markets (Worth, 2010).

These attacks have real consequences, and the world oil market recognizes the risk posed by these attacks. In February of 2005, a failed Al Qaeda attack on the Aramco facility in Abqaiq, Saudi Arabia, caused the price of oil on international markets to jump nearly two dollars per barrel (Cohen, 2007).

As grave as those threats are, perhaps the single greatest threat comes from Iran. The literature on this subject includes Congressional investigation of the risk. Some members of Congress feel that in response to any attack, Iran would retaliate by attempting to shut off the supplies of Middle East oil (Chairman, 2007). Those feelings are supported both by the public expressions of intent from Iranian officials, and by the capabilities of the Iranian military (Berman 2006; Cohen 2007). These are not idle threats. If Iran retaliated and shut down the Strait of Hormuz, it would mean the temporary loss of more than 15 million barrels of oil a day (Cohen 2007). Cohen goes on to describe just how effectively Iran has built a military arsenal with this capability in mind.

Iran boasts an arsenal of Iranian-built missiles based on Russian and Chinese designs that are difficult to counter both before and after launch. Of particular concern are reports that Iran has purchased the SS-N-22 Moskit/Sunburn anti-ship missile. The supersonic Sunburn is specifically designed “to reduce the target’s time to deploy self- defense weapons” and “to strike ships with the Aegis command and weapon control system and the SM-2 surface-to-air missile.”¹² Iran is also well stocked with older Chinese HY-1 Seersucker and HY-2 Silkworm missiles and the more modern C-802 anti-ship cruise missile (ASCM)—designs that Iran has successfully adapted into their own Ra’ad ad Noor ASCMs.

Iran has a large supply of anti-ship mines, including modern mines that are far superior to the simple World War I-style contact mines that Iran used in the 1980s. They include the Chinese- designed EM-52 “rocket” mine, which remains stationary on the sea floor and fires a homing rocket when a ship passes overhead. In the deep waters in the Strait of Hormuz, such a weapon could destroy ships entering or exiting the Persian Gulf. According to one expert, Iran “can deploy mines or torpedoes from its Kilo-class submarines, which would be effectively immune to detection when running silent and remaining stationary on a shallow bottom just outside the Strait of Hormuz.”¹³ Iran could also deploy mines by helicopter or small boats disguised as fishing vessels.

Mines are only one of a host of potential Iranian threats to shipping in the Persian Gulf. The naval commandos of Iran’s Revolutionary Guards are trained to attack using fast attack boats, mini-sub- marines, and even jet skis. The Revolutionary Guards also have underwater demolition teams that are trained to attack offshore oil platforms and other facilities. (Cohen 2007)

Even with the United States' extensive military power, U.S. intelligence estimates that Iran's military rearmament has given it the ability to shut off the flow of oil from the Persian Gulf temporarily (Berman, 2006).

Literature has examined the fungible nature of oil as an asset and how that increases the threat to the United States. Although the United States imports much of its foreign oil from friendly nations like Canada and Mexico (EIA, 2011a), the entire world supply would be impacted by a significant disruption anywhere in the oil market (Chairman, 2007). Should Iran or another actor temporarily interrupt the world wide flow of oil, if the United States chooses to respond, for example to open the Straits of Hormuz, the government will be forced to make very difficult choices. According to Thomas, "Reserve stores of petroleum and petroleum-based fuels would dwindle quickly—particularly during wartime operations—leaving the U.S. military unable to obtain suitable alternative fuels and rendering it virtually immobile" (2010).

2. Secondary Effects of Foreign Oil Dependence

This body of literature tends to focus on the importance of oil in general. There is no real discussion of the distinction between foreign and domestic oil supplies. It is necessary to consider this body of literature, in concert with the prior literature, in order to understand the secondary ramifications posed by dependence on foreign oil.

a. Dependence of Emergency Responders on Reliable Oil Supply

Of course, if the military is demanding all available petroleum resources, that leaves fire, police and ambulance services in short supply in the United States. Other, non-critical, demands for petroleum would be left completely unfulfilled (e.g., commuters, truckers and the airline industry). Emergency services in the U.S. are delivered via fire trucks, ambulances and police cars; all of those vehicles depend on access to gasoline or diesel fuel. So delivery of emergency services in the United States depends on oil. Additionally, during catastrophic events, when emergency services are most in need, the services' reliance on gasoline or diesel fuel increases significantly as they turn to generators to supply power in order to provide many of their services.

Disruptions are inevitable for any number of reasons, including geopolitical or terrorist attacks on critical energy infrastructure (Leotta, 2006).

On August 14, 2003, over 9,300 square miles, covering eight states and portions of Canada lost electrical power with virtually no warning (International Association of Fire Chiefs [IAFC], 2003). In New York City alone, emergency services responded to 91,000 9–1–1 calls during the outage (IAFC, 2003). Even in their reduced capacity, emergency services were called on to perform more than 30 distinct tasks: inter alia, elevator rescue, subway rescue, fire suppression, hazard calls, traffic accidents, welfare checks at hospitals, senior citizen homes, day care centers and prisons, providing power to critical care facilities, distributing water, opening emergency shelters for the elderly and helping the elderly up and down stairs (IAFC, 2003).

The firefighters were able to perform these actions because they had fuel in their vehicles and because most of their 911 dispatch centers and many fire stations had emergency power (IAFC, 2003). Of course, oil fueled those backup power systems. Emergency generators were the only means of pumping water to fight fires in some areas. Many stations relied on mutual aid agreements. Cleveland had an almost total loss of water, but by activating a statewide assistance plan, tankers and personnel saw them through (IAFC, 2003). Should the crises impact the U.S. broadly, this reciprocation of coverage would not be possible, incapacitating many first responders.

b. Impact of Natural Disasters

The effects of Hurricanes Katrina and Rita on the regionally impacted populations have been well documented. The second order effects further establish the homeland security implications of reliance on oil. The effects of these storms went far beyond the areas where the storm itself hit (Leotta, 2006). The storms showed the vulnerability of the oil supply chain well beyond the coasts directly hit by the storms. Nearly 1.6 million barrels a day of crude oil (between seven and eight percent of U.S. oil consumption) was produced by Gulf of Mexico federal offshore sites before the hurricanes struck (Leotta, 2006). Production was virtually halted in the wake of both storms, as production facilities were evacuated and wells were closed. By September 1,

at least one county in North Carolina was faced with 60 percent of its gas stations out of fuel (Leotta, 2006). The shortage was occurring hundreds of miles from the storm. Though the energy crisis was severe, it was not expected to last long. Nonetheless, it became necessary for the state energy office to convene all major agencies and require each to prepare a list of how they might curtail fuel consumption; agencies had to prioritize their fuel consuming activities (Leotta, 2006). The situation was sufficiently short lived to avoid a state of emergency.

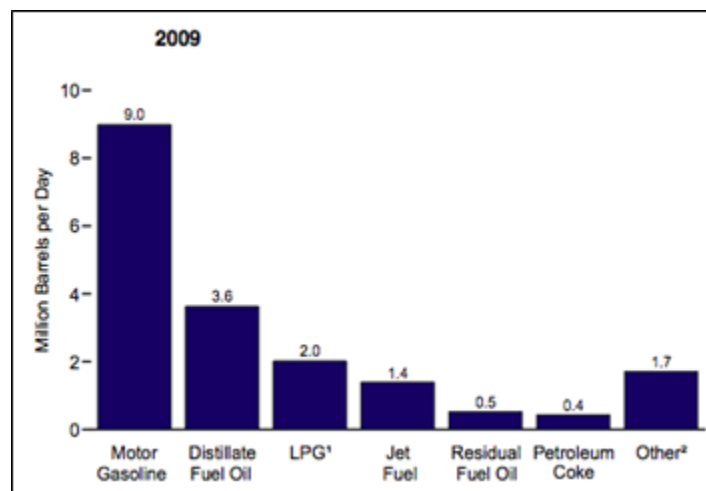
Had the fuel shortages persisted or worsened, the state would have been unable to provide the National Guard, who obtains its fuel through the state, with fuel for very long (Leotta, 2006). North Carolina was fortunate that it did not need to rely on the services of its National Guard during this crisis. One of the proposed solutions was to have first responders and other critical users enter into firm contracts for fuel (Leotta, 2006). Unfortunately, such an arrangement only works if there is sufficient fuel. If fuel supplies were limited, states would be forced to choose which of their vital operations, which critical needs of their populations, to forego.

While this body of literature looks at unintended disruptions to the supply of oil (e.g., hurricanes and accidental blackouts) there is no reason to believe the impacts would be diminished if the disruptions were intentional. Moreover, though not discussed in any literature, it is not difficult to imagine the magnification of devastation were an intentional disruption of the foreign supply of oil to coincide with a natural disaster.

B. OIL SOURCES AND USES

There exists a robust cataloging and compiling of both the various uses of oil in the United States as well as a breakdown of the sources of the oil used in United States. The U.S. Energy Information Administration (EIA) collects, organizes and makes available to the general public a cornucopia of data relating to oil consumption and production. All manner of data is tracked, including total oil used, oil imports, OPEC versus non-OPEC imports, by country OPEC imports, etc. For 2009, EIA data shows that the United States had net imports of 9.7 million barrels of crude oil per day (EIA, 2010a). The 9.7 million barrels of crude oil imported per day was from a total of 18.7

million barrels of crude oil used per day (EIA, 2010a). During the same year, 13.3 million barrels of oil were used per day for transportation purposes in the United States, with nine million barrels per day specifically used for motor gasoline (EIA, 2010a). The nine million barrels used every day for motor gasoline represented 48 percent of all U.S. petroleum consumption (EIA, 2009). The relative numbers have held fairly constant. In 2010, the U.S. consumed 19.1 million barrels of oil per day (EIA, 2011d), with nine million barrels per day used for motor gasoline (EIA, 2011e). In 2010, net imports accounted for 49 percent of U.S. oil consumption (EIA, 2011d). For a more detailed description of the uses of oil, see Figure 2.



1 Liquefied petroleum gases.

2 Asphalt and road oil, aviation gasoline, kerosene, lubricants, naphtha-type jet fuel, pentanes plus, petrochemical feedstocks, special naphthas, still gas (refinery gas), waxes, miscellaneous products, and crude oil burned as fuel.

Figure 2. Uses of Oil (EIA, 2010a, p. 148)

There is no significant body of literature challenging the veracity of the data provided by the EIA. There is, however, secondary literature that seeks to analyze the available data. For example, there is literature that focuses on comparing the amount of oil imported by the United States with its overall use of oil. In writing for the Truman National Security Project, Jonathan Powers (2010) uses the statistics provided by EIA to demonstrate the breadth of the national security hazards from dependence on fossil fuels, most specifically oil. Other authors have utilized the same EIA data to demonstrate the need and benefits that could result from switching to plug-in hybrid electric vehicles

(PHEV) (Brooker, 2010). Though not always with attribution, the media seems also to rely on the data provided by EIA. The *Wall Street Journal* ran an article discussing why an alternative-energy future may be far away and explained that one cause was the amount of fuel used for transportation¹ (Totty, 2010). The literature describing the sources and uses of oil in the United States is relatively complete and settled.

C. ACHIEVING ENERGY DEPENDENCE

Notwithstanding the difficulties created by dependence on foreign sources of oil, illustrated by history and decried repeatedly by political and military leaders, there has been little literature focused on achieving independence from a security perspective. There are some signs that might be changing. Recent practitioner based scholarly work has emerged that looks directly at the problem of ending U.S. dependence on foreign oil or oil outside of North American sources (Cowden, 2008; Thomas, 2010). These papers describe very broad frameworks for developing energy independence, but they do not discuss nut and bolt practicalities of how the country might arrive there from its present state.

There are also environmentally focused papers that discuss “green energy,” that give passing reference to the security implications in order to bolster the strength of their arguments (for example see Hensley, 2009). Some of the “green energy” literature describes the various policy considerations as they relate to exploring and/or encouraging alternative sources of energy for vehicles (Whoriskey, 2009). Whether vehicle specific, or energy use in general, the solutions involving “green energy” generally embrace local sources of energy, consequentially reducing dependence on foreign sources of energy. There is also analysis of policies concerning corn based ethanol (Hauser, 2007), geothermal energy (Sweet 2010) and electric vehicle infrastructure (Cote’, 2010). However, there is no real move in this literature to embrace security as a driver of change and to include that focus in their analysis. Therefore, the authors fail to leverage a view

¹ Totty refers to 3.3 billion barrels of gasoline used for transportation in 2009. That is not accurate, but would be consistent with the nine million barrels of oil used for motor gasoline (13.3 million barrels for total transportation) in the U.S. per day. At 365 days per year, that would roughly equate to 3.3 billion barrels of oil used for motor gasoline in 2009 per USEIA (EIA, 2010).

that could provide significant sources of political will. Furthermore, the literature that focuses on energy production largely misses the mark. Since only about 0.2 percent of the oil used in the United States is used for electricity production (EIA, 2010a, p. 152), absent some manner of translating that energy into a form usable by the transportation sector “green” sources of electricity production will not displace oil.

D. ADOPTION OF ALTERNATIVE FUEL VEHICLES

1. Large-Scale Efforts in the 1990s

There have been efforts in the past to bring about the adoption of EVs or other zero-emissions vehicles. There is some literature available that looks at and analyzes these past efforts. For example, in the 1990s, California, in a somewhat adversarial process, enacted a series of policies, including the requirement that a small percentage of new vehicles sold in California be zero-emissions vehicles (Calef, 2007). As time progressed towards the deadlines set by California, it became apparent that the industry was not going to meet the standards and therefore California shifted to an emphasis on low-emissions vehicles (Boyd, 1996). Also in the 1990s, with little public discussion, France engaged in a nonadversarial effort at bringing about the adoption of EVs (Calef, 2007). For a range of reasons, including technology that was not yet ready, the efforts failed in both France (Calef, 2007) and in California (Bedsworth, 2007; Calef, 2007). This body of literature is helpful in that it documents potential pitfalls. However, especially because technology plays an integral role in the analysis, these case studies are somewhat out of date.

2. Predictions of Adoption

The literature is replete with predictions of when EVs will or should encompass a certain percentage of the automobile market share. Al Gore concluded that it is possible to completely eliminate the internal combustion engine over a 10-year period if a concerted effort is made to do so (Gore, 1992). Most analysis focuses on a given market share based on the cost of oil or based on the cost of the EV batteries. One study determined that lithium ion batteries will drop in price from \$720/kWh to between \$405/kWh and \$445/kWh by 2020, resulting \$510 million in sales of EVs if oil trades at

\$70 per barrel and \$9 billion in EV sales if oil trades at \$200 per barrel (Haldis, 2009). Another, more optimistic analysis by automotive market research company CSM, predicted that by 2020, battery prices will cost only 20 percent of what they cost in 2009 (Hammerschmidt, 2009). Another study by UC Berkely predicted that EVs could make up as much as 64 percent of the new-car market share by 2030 (Peckham, 2009).

There has even been discussion of what it might take to meet President Obama's target of one million EVs on the road by 2015 (Daigneau, 2011). A study by Credit Suisse, a financial services company, anticipates a faster development of the market, predicting that there will be five million EVs on the road by 2020 (Sherman, 2011). This body of literature offers predictions of where the country might end up with some general explanations of the factors that impact which future materializes, but it fails to provide sufficient analysis of the interplay of those factors and does not adequately describe how those factors can be utilized purposefully to achieve the wide scale adoption of EVs.

3. Recent Stimulus Money

One effort at increasing the market share of EVs was the recent stimulus package; \$2.4 billion in Recovery and Investment Act money was dedicated to advances in EV batteries, building the domestic EV industry, and building charging stations² (Lee, 2010). Data has been collected capturing the amount of investment and in some cases the specific returns or anticipated returns.

One area that has received significant attention is recharge infrastructure. Though EVs can be charged at home, many EVs currently have limited range compared to their internal combustion counterparts. For example, the Nissan Leaf can travel approximately 73 miles³ on a single charge (DOE, 2011a), though some models of the Tesla Roadster can travel 300 miles on a single charge (Tesla, n.d.). The phenomena known as "range anxiety" can diminish utilization of EVs, with use well below the actual range of the EV,

² These funds are separate from the funds used to give \$7,500 in tax rebates to customers who purchase EVs (U.S Department of Energy [DOE], 2011a).

³ It is not uncommon to see articles discussing the Leaf describe it as achieving 100 miles to the charge. Though under certain conditions, Nissan claims this to be true, what is probably being cited is the miles per gallon equivalency of the Leaf, which has been calculated to be the equivalent of 99 mpg (DOE, 2011a).

making a recharge infrastructure critical (Botsford, 2009). There are various types of recharge facilities. The cost of the slow charge facilities is significantly cheaper than for fast charge. In fact, some EVs can slow charge without any change to a standard electrical outlet (Dickerman, 2010; German, 2010). As shown in Figure 3, as the speed of the charge goes up, so does the required voltage/amperage output, which necessitates more expensive facilities.

table 3. Typical set of charging options developed for an EV.				
EVSE	Utility Service	Usage	Charge Power (kW)	Time to Charge
Level 1	110 V, 15 A	Opportunity	1.4	18 hours
Level 2	220 V, 15 A	Home	3.3	8 hours
Level 2	220 V, 30 A	Home/Public	6.6	4 hours
Level 3	480 V, 167 A	Public/Private	50-70	20-50 min

Figure 3. Recharge Levels and Time to Charge (From Dickerman, 2010)

One estimate of the cost⁴ of recharging stations can be taken from a project underway in Portland, Oregon. Oregon is using a two million dollar federal grant (stimulus money) to build 42 “quick charge” stations along the I-5 corridor, ensuring no gap greater than 50 miles (Oregon, 2010). That averages out to \$47,619 federal dollars per station. These stations are designed to charge an EV battery to 80 percent capacity in a 20 to 30 minute period (Oregon, 2010).

A project funded in part by the U.S. Department of Energy (DOE) provides an estimate for the cost of building slow charge stations. Given the total cost of \$230 million (of federal money) to build 15,000 charging stations, each station costs approximately \$15,333; however, that also includes 310 quick charging stations (Read, 2010), which are more expensive. Assuming the quick charging stations cost \$47,619 each, the cost per station of the ordinary charging stations would be approximately \$14,652 federal dollars.

⁴ The cost described here, is the cost to the federal government. In order to receive the stimulus funds, the recipients had to match the funds dollar for dollar from private or state/local government sources (Lee, 2010). Therefore, the total cost is actually twice that represented here, but the cost to the federal government is accurately described.

The DOE has released its analysis of the Recovery and Investment Act stimulus funds. In its estimation, it is on track to meet President Obama's goal of one million EVs by 2015 (DOE, 2011b). The scientific community has taken note of the anticipated benefits from the stimulus fund, highlighting certain DOE predictions. One such prediction is that a battery capable of powering a vehicle 100 miles, which costs \$33,000 today, will cost just \$16,000 by the end of 2013 because of those stimulus fund investments (Stimulus, 2010).

This body of literature is fairly thin. It consists mostly of the documentation of data, without much analysis. It is sufficient to provide a qualitative assessment of the bang for the buck in estimating the expense of building a recharge infrastructure to support EVs. The research does not attempt to extrapolate forces like economies of scale that might reduce the cost of infrastructure development. It also fails to analyze whether or not the recharge facilities can be expected to be or become economically self-sustaining and thus whether pure commercial forces can be relied upon in the future to build the recharge infrastructure. The creation of recharge infrastructure and an in-depth description of range anxiety are addressed in more detail in Chapter V.

E. SUPPLY AND DEMAND—ECONOMICS OF CHOICE

1. Elasticity of Gasoline

Academics and the federal government have both examined the elasticity of gasoline. That is, what happens to the amount of gasoline sold when the price of gasoline goes up or down. There are a multitude of studies on this topic; however, two papers have looked at many of the gasoline elasticity studies conducted over the past few decades in an effort to summarize the field. These meta-studies essentially conclude that gasoline elasticity is two pronged. There is a short-term affect that is particularly small and then a long-term affect that is somewhat larger (Espey, 1996; Goodwin, 2003). The study by Espey focuses on elasticity in the United States, while Goodwin's study is focused on the United Kingdom. Goodwin's study also looks at the reduction in traffic volume from an increase in gasoline price. Morris (2007) has also described this understanding of the elasticity. Speaking at an EIA conference, he described the same two-phased elasticity.

In the short run, elasticity was between zero and -0.5, and in the long run, it was between -0.5 and -1.5. Put another way, in the short run, a gasoline price increase of 10 percent will reduce the quantity demanded by two percent. In the long run, a sustained 10 percent increase in the price of gasoline will result in a six percent decrease in consumption (Federal Trade Commission [FTC], 2005).

The elasticity of gasoline is well documented. What this body of literature does not address is the effect, if any, that gasoline prices have on consumer vehicle choices.

2. Gasoline Price and Vehicle Choice

Around the turn of the millennium, carbon tax and other policy discussions about global warming brought the question of gasoline elasticity into sharp focus (Kayser, 2000). Rather than look just at more traditional measures of elasticity, the literature evolved in an effort to account for income disparities, miles driven and, ultimately, vehicle choice. Gasoline demand and the demand for automobiles were modeled as a joint decision (Kayser, 2000). By also accounting for income, it emerged that there was not a uniform elasticity measure, but rather elasticity varied across the income distribution (Kayser 2000). Importantly, it was also determined that gasoline demand responds to changes in the price of gasoline in large part by modifying the fuel efficiency of the car fleet rather than through an adjustment of miles traveled (Jehani & Sibdari, 2010; Kayser, 2000). In fact, it has been determined that the number of miles driven bears almost no relation to gas price changes (Jehani & Sibdari, 2010).

The federal government has also explored this topic and come to similar conclusions. Looking at the period from 2003 through 2007, the Congressional Budget Office (CBO) determined that the 100 percent increase in gasoline prices had induced motorists to adjust the types of vehicles they purchased (CBO, 2008). They note that in response to consumer demand, the fuel economy of new cars increased in nearly every new model year since 2000, despite a slightly larger annual price increase for more fuel-efficient vehicles (CBO, 2008). The report specifically notes the potential policy advantages that tax increases on the price of gasoline have over increasing the federal corporate average fuel economy (CAFE) standards. That advantage stems from more

direct alignment with market forces (CBO, 2008). The literature also notes that in order for elasticity to strengthen, consumers must have substitutes that are easy to switch to (FTC, 2005).

Another government sponsored review of vehicle electrification focused on the different economic effects of various choices (e.g., plug-in hybrids or pure EVs), opportunity charging versus charging at night versus dynamic charging as the vehicles drive along stretches of road, etc (Brooker, 2010). That analysis concluded that the most economic future lay in dynamic charging, but the study ignored infrastructure costs, used an exceptionally conservative estimate of only a three percent reduction per year in battery cost, and, while allowing other factors to change over time, used a fixed gasoline price based on the average cost of gasoline in 2008 (Brooker, 2010).

As with pure elasticity, hard numbers have been developed in this body of literature. If gas price increases by 10 percent, the demand for SUVs will decrease by 13.7 percent and the demand for hybrid cars will increase by 9.1 percent (Jeihani & Sibdari, 2010).

This body of literature is relatively new and to some degree at risk of becoming stale due to fast-paced changes. The availability of alternative vehicles, EVs versus hybrids for example, quickly shifts the dynamic, especially if economies of scale are reached. However, the demonstrated principle of changes in consumers' choice of vehicle adds significant value by providing a reasoned model to enhance the predictive process. What remains absent is both a focus on the risks and costs of energy independence (though it is often mentioned in passing) and an analysis of specific targeted policy choices and how they might bring about change—policies that raise the price of gasoline, lower the price of EVs, and otherwise promote the adoption of EVs.

F. CONCLUSION

Existing literature provides ample support establishing the extent of and threat posed by the United States' dependence on foreign oil. Current literature sufficiently describes the various uses petroleum is put to in the United States. There is some discussion focused on alleviating the dependence on foreign oil by encouraging

alternative energy and alternative energy vehicle adoption, but there is a glaring omission. The focus of the literature is really on economic and environmental factors and benefits. It does not look at EV adoption with an eye truly focused on U.S. security. The existing literature also fails to use that security perspective to consider specific policy choices that might be made to increase the pace of EV adoption in order to bring about energy independence.

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III. METHOD

A. CASE STUDY CONSIDERED

The case study method is one potential method to assess how policy choices can be used to bring about the shift to EVs. There is data available and have been studies made of the efforts of California and France to move toward zero-emissions vehicles in the 1990s (Bedsworth, 2007; Calef, 2007). There are limitations to this method that make it less than ideal. In the first instance, the adoption of EVs is connected to the current state of technology. California's program had to be redirected to low emissions vehicles rather than zero emissions, precisely because of technology limitations (Boyd, 1996). Those efforts were before the advent of the Tesla Roadster, Nissan Leaf, Chevy Volt and other market ready EVs. The technology of the 1990s does not resemble present day EV technology. For that reason, the case study method is not an ideal choice.

B. MODELING CHOSEN

This thesis will utilize predictive modeling to examine the effect different policy choices would have on the adoption of an EV fleet in the United States, which would bring about U.S. energy independence. Predictive modeling provides a mechanism for policymakers to visualize the likely effect of policy choices as an aid in determining the most effective combination of policy choices to bring about EV adoption and thereby achieve energy independence.

The thesis will utilize inductive modeling based on historical socio-economic and vehicle data. A model, based on the concept presented by Jeihani and Sibdari (2010), will be created to predict the trend of increased sales of EVs that would result from varying levels of increased gasoline prices and decreased EV prices. The system of vehicle choice is extremely complex. There is no expectation that the model will produce numbers that predict future sales with exact precision. Rather, the model is expected to be sufficiently accurate to establish turning points. On a graph showing sales, the model should be able to show the "hockey stick" affect accurately, the point where the rate of sales increases dramatically. The model can then be used by anyone, inputting different

assumptions about the future and accounting for different policy choices intended to speed up the adoption of EV sales. Specifically, the model will allow the policymaker to view a predicted affect from a near limitless number of variations of gasoline excise tax decisions that feed into a rebate, lowering the cost of EVs.

C. LIMITATIONS OF MODELING

As every mutual fund prospectus warns, past performance is no guarantee of future success. Predictive modeling has the same inherent risk. The modeling method utilizes past data results to predict future results. It is inevitable that there are other, unaccounted for, contributors to the observed historical behavior. What is not known is how significant those other forces are. It is also possible that people will simply decide to behave differently. For example, if the issue becomes politicized and people modify their behavior accordingly, or groups with opposing financial interests flood the discussion with information that is either untrue or misleading, a model relying on past behaviors may lose its efficacy. Finally, it is possible that the historical data is accurate, but only within the ranges that have historically occurred. For example, assuming the largest gasoline price increase accounted for in creating the model is X, when a model used to predict the results that would occur for a gasoline price increase of 2X, it is possible the model loses its efficacy.

Though predictive modeling entails risks, those risks are somewhat mitigated by the breadth of the data reviewed and by the range of factors considered. The Jeihani and Sibdari (2010) concept incorporates far more than just the change in demand resulting from a gasoline price increase; it incorporates vehicle type and fuel efficiency, household disposable income and unemployment rates as well. In fact, by use of a stand-alone catchall constant, to some degree it incorporates all factors affecting choice, even where those factors are indeterminable. By including these additional criteria, the formula reduces the chance there is some other factor being overlooked.

Predictive modeling provides a tool for policymakers, giving them a logical framework for assessing the most likely outcome of their decisions. Though not perfect, use of historical factual data greatly improves upon gut instinct, or other haphazard efforts at predicting the outcome of policy decisions.

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IV. RESULTS

A. PREMISE OF THE PREDICTIVE MODEL

The goal of this research is to provide a rigorous basis for federal policies that would accelerate the nation's transition from gasoline internal combustion engines to a national fleet of EVs. By eliminating the demand for motor gasoline, the overall daily demand for oil in the U.S. would approximately equate to the amount of oil the U.S. produces each day. The primary levers of any federal policy are likely to be the price of gasoline and the price of EVs.

In this chapter, an effort is made to model the influences on vehicle choice, focusing on the consumer's decision to purchase a more fuel-efficient vehicle. The model looks at the basic costs of vehicle ownership as well as the more complex factors of vehicle choice. The methodology will provide a model that is accurate at lower volumes of sales, recognizing that given the overall complexities of the system, it cannot predict precise sales numbers. The model will also create a general methodology where the practitioner can incorporate additional factors, or utilize different assumptions, and have a grounded basis to predict the results flowing from those choices.

The model developed by Jeihani and Sibdari (2010) provides the conceptual basis for development of a predictive model. They utilize a binary vehicle choice model in order to provide a quantitative framework to assess the various factors that might influence consumer transition choices (Jeihani & Sibdari, 2010). In their work, the relative probability, P , of choosing one type of car, denoted by the subscript e , to another type of car, denoted by the subscript c , for any given household, i , is captured by the following formula:

$$\frac{P_{ie}}{P_{ic}} = \frac{\left(e^{A_e + B_e K_i + C L_e}\right)}{\left(e^{A_c + B_c K_i + C L_c}\right)} \quad (1)$$

Where A , B , and C are constants, K represents the characteristics of the buyer, and L represents the characteristics of the car. The constant A in Equation (Eqn.) 1 can be related to the type of car that, in effect, represents a bias that a consumer might have

towards a vehicle. For instance, range anxiety might well make a consumer wary of an EV and this may be captured in the constant A , driving down the probability of choosing an electric car. Likewise, styling, or fuel economy might well have an influence, as could environmental considerations.

Though Jeihani and Sibdari (2010) used only one standalone constant, A , one could imagine including a great many such constants in an attempt to capture a greater range of consumer biases. One could imagine developing an input to the car characteristics that would include a national defense cost per vehicle, where that cost reflects the investment made by the DoD to maintain shipping lanes, providing support to governments that are critical for oil imports, etc. Those costs would then appear as a price per vehicle, which could be denoted as a national defense cost, ND , that is weighted by the fuel efficiency of a particular vehicle. Likewise, one could attempt to capture the economic costs of the oil trade deficit to the nation, the approximately one billion dollar daily deficit. Those costs could also appear as a price per vehicle and, denoted as a trade imbalance cost, TI , would also be weighted by a vehicle's fuel efficiency.

The constant B weights the characteristics of the buyer towards certain car types, while the constant C weights the vehicle characteristics.

The constant K_i captures household characteristics including both employment status and income while L captures the initial vehicle cost and the cost per mile for vehicle locomotion.

B. DEVELOPMENT OF THE PREDICTIVE SALES MODEL

Rather than calculating the relative probability of choosing one car over another, the model presented in this section solves for sales volume of a particular vehicle class. In all, three vehicle classes are looked at, SUV, hybrid, and EV. Historical data on both SUV and hybrid vehicles is used to establish coefficients that allow a least squares fit on that model to that historical data. Where specific vehicle averages are necessary, for example average sales price of the class of vehicle, a representative vehicle was chosen. The Ford Explorer represents the SUV class of vehicles, and the Toyota Prius represents the hybrid class of vehicles.

This approach allows the assignment of consumer coefficients from sales data and presumes that these coefficients will remain the same for the foreseeable future. As there is insufficient data for a meaningful historical analysis of EV sales, the coefficients derived for hybrid vehicles are used as a proxy in predicting EV sales, assuming the two are closely related. Those coefficients are then used in the model to predict future sales of EVs.

Notably, Jehani and Sibdari (2010) did not adjust for inflation when analyzing historical data they collected. Adjusting the historical data used herein was considered; however, the model is designed to reflect people's choices at a fixed point in time. When consumers go to purchase a vehicle they are considering what the price of gasoline currently is, what their income currently is, etc. They may also be considering what they expect the value of those items to be in the future, but they are concerned with absolute amounts. The model shows fixed choices from moment to moment. If high levels of inflation were anticipated going forward, that could influence consumer purchasing decisions in general (e.g., buy assets rather than hold onto money), but none of the purchase periods analyzed in this thesis took place during periods where inflation was particularly high. From 1991 through 2010, no calendar year saw inflation greater than 4.2 percent (U.S. Department of Labor, 2011). In fact, adjusting for inflation would flatten the changes in the economic data. Rather than reflecting reality, it would actually skew the reality that the consumer faced at the time of their purchase decision.

Assuming a linear relationship between the change in the number of hybrid vehicles sold in any year, ΔS_{hy} , and any of the influencing parameters, as was the basis for the Jehani and Sibdari (2010) model, the number of hybrid vehicles sold in any year, S_{hy} , can be modeled and the model be used to project future sales. Future sales depends on many economic and perception factors. Among the national economic parameters the Jehani and Sibdari (2010) model included were: the median household income I , in the modeled year, the unemployment level U , and the price of gasoline G . For the vehicular economic parameters the model included the gas mileage, M_{hy} , as represented by the number of miles the vehicle can travel per gallon of gasoline and the hybrid vehicle price P_{hy} . Finally, all parameters associated with customer perception such as comfort,

reliability, social appearance, environmental stewardship, etc. were lumped into a single coefficient A_{hy} . In essence, the coefficient represents the total combination of factors the consumer is considering that have not been specifically accounted for elsewhere in the equation.

Another way to look at the effect of policy choices is by examining the fraction of new sales, ΔS_{annual} , in any year relative to the total sales S_{annual} . This fraction is the *sales strain*, and is represented by:

$$\varepsilon_{sales} = \frac{\Delta S_{annual}}{S_{annual}} \quad (2)$$

A linear relationship between the sales strain and any influencing parameter is the simplest approach to modeling the sales figures. For example, the effect of household income, I , on the sales strain of hybrid vehicles when isolated from other parameters that influence sales, would be:

$$\frac{\Delta S_{hy}^I}{S_{hy}} = B_{hy} I \quad (3)$$

Where ΔS_{hy}^I is the change in the sales figures of hybrid vehicles due to the change in household income. As the overall sales figure S_{hy} increases so does the change in that figure due changes in any parameter such as I . The fundamental assumption in Eqn. (3) is that ΔS_{hy}^I varies linearly both with I and S_{hy} . The coefficient B_{hy} is a proportionality factor to be derived empirically using historic data.

The effect of the price of gasoline, G , and vehicle mileage can be combined to provide the cost per mile driven CPM_{hy} where:

$$CPM_{hy} = \frac{G}{M_{hy}} \quad (4)$$

Dependences similar to Eqn. 3 for the effects of U , CPM_{hy} and P_{hy} on the sales figures can be derived to provide ΔS_{hy}^U , $\Delta S_{hy}^{CPM_{hy}}$ and $\Delta S_{hy}^{P_{hy}}$, which are the change in the sales figures when each of the representative parameters is isolated from the others. The proportionality coefficients to be assigned to these dependences are C_{hy} , D_{hy} and E_{hy} respectively. All three coefficients need to be determined empirically using historic data.

The combined effect of all these parameters on the annual sales figures of hybrid vehicles can be obtained by superposition or a simple addition:

$$\Delta S_{hy} = (B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy})S_{hy} \quad (5)$$

Eqn. 5 can now be integrated for S_{hy} , then adding A_{hy} , the integration coefficient, which is described above, to provide:

$$S_{hy} = \exp(A_{hy} + B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy}) \quad (6)$$

Notably, this approach results in an exponential relationship between sales volume and income, unemployment, fuel costs and purchase price. Taking the natural log of this equation yields:

$$\ln(S_{hy}) = A_{hy} + B_{hy}I + C_{hy}U + D_{hy}CPM_{hy} + E_{hy}P_{hy} \quad (7)$$

Note that Eqn. 7 is the immediate result of the integration of Eqn. 5. However, Equation 6 was shown first to show the relationship between this derivation and the model presented by Jehani and Sibdari (2010). This expresses the relationship between the various parameters that are likely to influence the sales volume and the sales volume itself. Actual numerical values can be determined after obtaining the values of the coefficients B_{hy} , C_{hy} , D_{hy} and E_{hy} , with an offset factor given by A_{hy} . To derive the five empirical coefficients of Eqn. (7), one needs to obtain historical data concerning household income, unemployment, price of gasoline, gas mileage and car prices for at least five years. To the extent data is available, a similar equation can be derived for each vehicle model or model group.

The equation representing the sales figures of SUV vehicles was derived similarly to Eqn. (7) to yield:

$$\ln(S_{SUV}) = A_{SUV} + B_{SUV}I + C_{SUV}U + D_{SUV}CPM_{SUV} + E_{SUV}P_{SUV} \quad (8)$$

Again, the coefficients A_{SUV} , B_{SUV} , C_{SUV} , D_{SUV} , and E_{SUV} are empirical coefficients. Similar to those of the hybrid vehicle, they are to be derived using at least five years of historical data.

Unlike SUVs and hybrid vehicles, the available historic data on the sales volume of EVs is inconsistent with extremely small numbers. Consequently, those figures were

not considered reliable for the purpose of projecting future sales of EVs and the potential response to market-changing policies. Instead, the coefficients derived for the hybrid vehicle using historical data were retained as proxies for the EV sales volume model. It is reasonable to presume that factors influencing people’s decision to purchase hybrid vehicles will similarly influence their decision to purchase EVs. As with hybrids, it is likely that the first consumers to purchase EVs do so for a myriad of concerns (e.g., environmental, status). As sales of hybrids grew, economic forces such as declining vehicle price and increase in gasoline would have become the dominant market drivers. The same is presumed to be true with EVs. Therefore, only one parameter from the hybrid model Eqn. 7 was replaced. CPM_{hy} was replaced with CPM_{EV} , which was derived using the representative cost of electricity per $kWhr$ and the number of miles driven by the EV per $kWhr$. Accordingly, the model describing the sales volume of electric vehicle is represented by:

$$\ln(S_{EV}) = A_{hy} + (B_{hy} \times I) + (C_{hy} \times U) + (D_{hy} \times PM_{EV}) + (E_{hy} \times P_{EV}) \quad (9)$$

The coefficients representing the sales volume of hybrids (Eqn. 7), and consequently EVs, and SUVs (Eqn. 8) were derived using historic data. Table 1 contains the historic data used, encompassing the years 1991 to 2010 for SUVs and 2000–2010 for hybrids. More than five years of data was available for each vehicle group. With only five years available, the five coefficients of each model (Eqns. 7 and 8) could be determined by solving five algebraic equations. With additional years available, the coefficients could be determined by fitting $\ln(S_{hy})$ and $\ln(S_{SUV})$, as determined by Eqns. 7 and 8 respectively, to the sales volumes as shown in Table 1, through adjustment of the coefficients of these equations until the overlap between the historic data and the analytic data is optimized.

Figures 4 and 5 graphically represent the outcome of the optimal fit between the actual sales figures and the modeled figures. Optimization was achieved by minimization of the root mean square of the differences between actual and modeled figures. Table 2 shows the coefficients of the two models as derived through this analysis.

As previously explained:

- A_{hy} = all consumer preferences and choice factors not specifically addressed elsewhere in the equation,
- S_{hy} = the sales volume of hybrids,
- B_{hy} = weight factor for societal annual income,
- I = societal average annual income,
- C_{hy} = weight factor for unemployment,
- U = total unemployment,
- D_{hy} = cost of locomotion factor,
- PM_{hy} = price per mile for locomotion,
- E_{hy} = weight factor for price of hybrid,
- P_{hy} = price of hybrid vehicle

Table 1. Historical Data for SUVs and Hybrid Vehicles

year	income \$ ^^	Gas Price \$/gallon **	SUV Sales ***	Hybrid Sales ^	Total Un- employment ^^	SUV Price \$ †	Hybrid Price \$ ††	Hybrid MPG †††	SUV MPG §
1991	30,126	1.098	1,095,000		8628000	15,747			16
1992	30,636	1.087	1,003,000		9613000	16,692			16
1993	31,241	1.067	1,311,000		8940000	17,550			17
1994	32,264	1.072	1,623,000		7996000	18,860			16
1995	34,076	1.103	1,816,000		7404000	22,305			16
1996	35,492	1.192	1,890,000		7236000	21,170			16
1997	37,005	1.189	2,450,000		6739000	21,485			16
1998	38,885	1.017	2,581,000		6210000	21,560			16
1999	40,696	1.116	2,831,000		5880000	22,070			16
2000	41,990	1.462	3,143,000	9,350	5692000	23,480	19,995	41	16
2001	42,228	1.384	3,450,000	20,282	6801000	25,210	19,995	41	17
2002	42,409	1.313	4,191,000	36,035	8378000	24,585	19,995	41	16
2003	43,318	1.516	4,118,000	47,600	8774000	26,285	19,995	41	15
2004	44,334	1.812	4,713,000	84,199	8149000	26,600	20,295	46	15
2005	46,326	2.24	4,084,000	209,711	7591000	27,165	21,275	46	16
2006	48,201	2.533	3,757,000	252,636	7001000	26,530	16,213*	46	16
2007	50,233	2.7	4,231,000	352,274	7078000	25,370	20,601*	46	16
2008	50,303	3.26	3,987,000	312,386	8924000	26,495	21,500	46	16
2009	49,777	2.36	2,296,000	290,271	14265000	28,470	22,000	46	16
2010	50,000	2.79	3,000,000	274,210	14825000	29,280	22,800	50	17

*Includes weighted average of rebate that was offered during some or all of the year.

	Legend for Table 1:
**	Gas price \$/gallon: From Jeihani, 2010; U.S. Energy Information Administration; 2011b
***	SUV sales: From U.S. Department of Energy, n.d. (only applicable to years 1991–2009. Year 2010 is an estimate).
^	Hybrid sales: From U.S. Department of Energy, 2011c
^^	Total unemployment: From Bureau, n.d.
^^^	Income: From Census, 2009 (only applicable to years 1991–2009. Year 2010 is an estimate).
††	Hybrid price: From 2001 Toyota Prius, 2006; 2002 Toyota Prius, 2006; 2003 Toyota Prius, 2006; 2004 Toyota Prius, n.d.; 2005 Toyota Prius, 2006; 2006 Toyota Prius, n.d.; 2007 Toyota Prius, n.d.; 2008 Toyota Prius, n.d.; 2009 Toyota Prius, n.d.;
†	SUV Price: From 1991 Ford Explorer, n.d.; 1992 Ford Explorer, n.d.; 1993 Ford Explorer, n.d.; 1994 Ford Explorer, n.d.; 1995 Ford Explorer, n.d.; 1996 Ford Explorer, n.d.; 1997 Ford Explorer, n.d.; 1998 Ford Explorer, n.d.; 1999 Ford Explorer, n.d.; 2000 Ford Explorer, n.d.; 2001 Ford Explorer, n.d.; 2002 Ford Explorer, n.d.; 2003 Ford Explorer, n.d.; 2004 Ford Explorer, n.d.; 2005 Ford Explorer, n.d.; 2006 Ford Explorer, n.d.; 2007 Ford Explorer, n.d.; 2008 Ford Explorer, n.d.; 2009 Ford Explorer, n.d.; 2010 Ford Explorer, n.d.
†††	Hybrid MPG: After Find a Car, n.d.
§	SUV MPG: After Find a Car, n.d.
*	Information to perform weighted average for rebate: After Federal Tax, n.d.

Figures 4 and 5 show that, after optimization of the coefficient, Eqns. 7 and 8 yielded generally good approximations of the actual sales data.

Although the match between the actual and modeled sales volume is good, its application is limited. One should note that the two models (Eqns. 7 and 8) are independent of each other (i.e., as modeled, the sales of one group does not affect the sales of the other group (non-cannibalization)). Such independence is justified when the sales volume of hybrids or EVs is small relative to the total vehicle market; however, when the sales of one group overwhelm the market, the model must be reexamined. This failure of the model would occur at some point as the market responds so favorably to government policies that the use of internal combustion engines is almost completely abandoned in favor of EVs. Lacking a detailed analysis of the points of failure, it is assumed herein that the model should be used primarily as the predictor of trends (i.e., significant increase or decrease in the sales of certain vehicle groups, rather than the predictor of actual sales volumes).

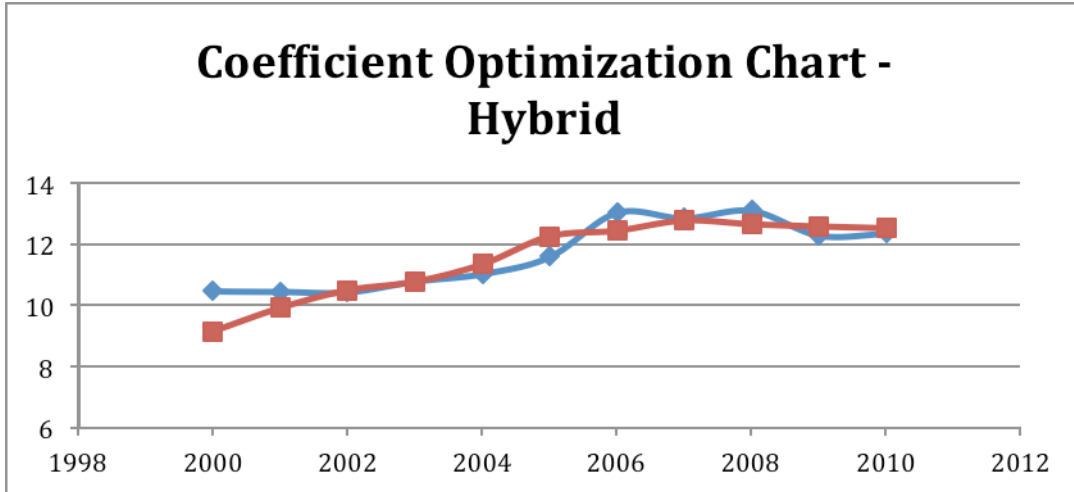


Figure 4. Comparison of the Variation of $\ln(S_{hy})$ with Year of Sale as Derived by Model (blue) with Historic Data (red).

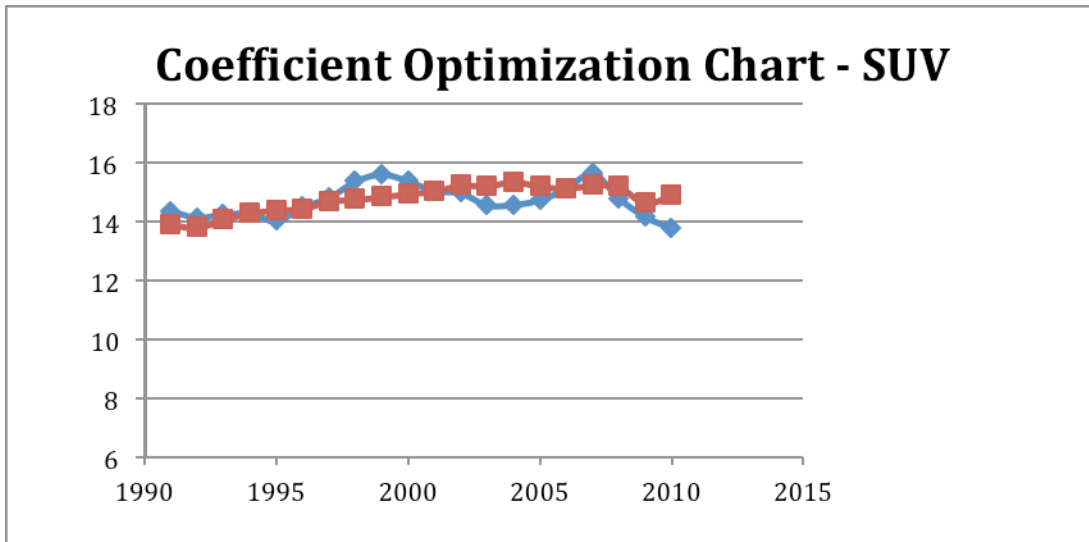


Figure 5. Comparison of the Variation of $\ln(S_{SUV})$ with Year of Sale as Derived by Model (blue) with Historic Data (red)

The resulting coefficients are contained in Table 2.

Table 2. Coefficients of the Sales Volume Models (Eqns. 7 and 8) of Hybrid and SUV Vehicles as Derived by Fitting These Equations to Historical Sales Data (Table 1)

	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Hybrid/electric	3.6	$2.16 \cdot 10^{-4}$	$-1 \cdot 10^{-13}$	31.1	$-1.66 \cdot 10^{-4}$
SUV	13.36	$2.01 \cdot 10^{-4}$	$-1.4 \cdot 10^{-7}$	-10.8	$-1.97 \cdot 10^{-4}$

Note that D_{hy} , which represents the response of the hybrid vehicle sales figures to gas prices, is positive whereas D_{SUV} is negative. This is intuitively plausible and represents the expected fact that higher gas prices provide an incentive for the purchase of hybrid or electric vehicles whereas they provide a disincentive to the purchase (or ownership) of SUVs. This is the basis for the government policy to be proposed below.

C. APPLICATION OF THE MODEL TO FORECAST SALES

The hybrid vehicle sales volume model (Eqn. 7) was used to project future sales volumes of EVs and the response to various government policies. To this end, the various columns of Table 1 were filled using projected data (e.g., expectations of future median household income or unemployment levels). The government policy choices, the gasoline excise tax per gallon and the rebate to the buyers of EVs, are parameters that can be adjusted by the user to achieve a desired result (e.g., rapid growth in the sales of EV or rapid decline in the use of gasoline).

Although the model was tested using a wide variety of parameters, the following parameters were ultimately selected as representing a good balance of the positive and negative effects of available policy choices and conservative assumptions about future economic conditions. The assumptions used herein are as follows:

- The gasoline excise tax is \$2 per gallon in 2012, \$4 the following year, and \$5 in 2014 through 2018. (The use of funds collected through the tax, for example, offsetting the expense of the tax for low income individuals, is discussed in detail in Chapter V.)
- The EV price for 2011 uses the Manufacturer's Suggested Retail Price (MSRP) of the entry-level 2012 model year Nissan Leaf, \$35,200 (Nissan) and a three percent annual decrease in price thereafter. The expected MSRP does not include the government subsidy described below. This decrease is a conservative number considering the anticipated rapid change in volume, which will create economies of scale. However, this reflects a similar conservative determination made by Brooker, that the price of EV batteries will decrease by three percent per year (2010).
- Though soon after publication of this work, actual 2011 sales volumes may be available for EVs, the 2011 sales volume used here was obtained from the predictive model. The 2010 EV sales were estimated as 10 percent of the hybrid vehicles sales volume of 274,210 (DOE, 2011c).

- The 2011 total sales cost of the EV reduces the MSRP described above by the \$7,500 tax rebate that is currently available for purchase of an all-electric vehicle. Beginning in 2012 and thereafter, the total cost of the EV begins with the MSRP price described above and further reduces it by \$15,000, the amount of tax rebate used for this particular predictive analysis.
- Beginning in 2008 with an EV cost per mile of three cents (Electric, 2007), the model assumes a three percent annual increase in the price per mile for the EV. This presumes the cost of electricity will increase with increased demand, though this could be offset if batteries become more efficient at recharging or otherwise become more efficient.
- Gallons of gas sold per year begins with the actual gallons sold at retail in 2009, 18,176,124,000 gallons (EIA, n.d. a.), leaves the amount constant for 2010 and 2011, and assumes a five percent decrease in 2012, the first year a gasoline tax is imposed in this model. The five percent decrease assumes that imposition of the two dollar tax will induce a decrease in the demand for gasoline. Each year beyond 2012, the decrease in gasoline sales is determined by multiplying the number of EVs sold the prior year by 490 gallons. The average driver drives 13,476 miles per year (Federal Highway Administration, 2011). Current CAFE standards provide for an average vehicle gas mileage of 27.5 mpg (National Highway Traffic Safety Administration, n.d.). Therefore, multiplication of these two figures provides an estimate of the gallons of gasoline used by each vehicle per year. Assuming that each EV sold the previous year will reduce sales of gasoline-powered vehicles by one that equates to 490 fewer gallons of gasoline sold in the current year for each EV sold the prior year. In fact, the decrease is likely higher due to drivers who purchase EVs throughout the year and other factors, but this is the estimate used in the model. A further benefit of this assumption is that it indirectly introduces a coupling between the sales volume of EVs and sales of other vehicles. It assumes that sales of EVs will cannibalize sales of all other vehicles; however, this is an incomplete and very partial coupling that does not overcome the weakness of the model as indicated above.
- The unemployment factor begins in 2010 with the published total unemployment figure of 14,825,000 (Bureau of Labor Statistics, n.d.) and assumes a one percent reduction each year.
- The income factor uses the 2009 median annual income of \$49,777 (Census Bureau, 2009) and assumes a one percent increase each year.
- The base price of gasoline, prior to the introduction of the excise tax, begins with an average price of three dollars per gallon in 2011 and

increases the price by five percent per year. That assumes that the world oil market will continue to see an increase in demand even as demand in the U.S. declines.

Applying the policy and economic assumptions above to Eqn. 7, taken together with the coefficients from Table 2, provides the projections of sales of EV (Figure 6) between 2011–2018.

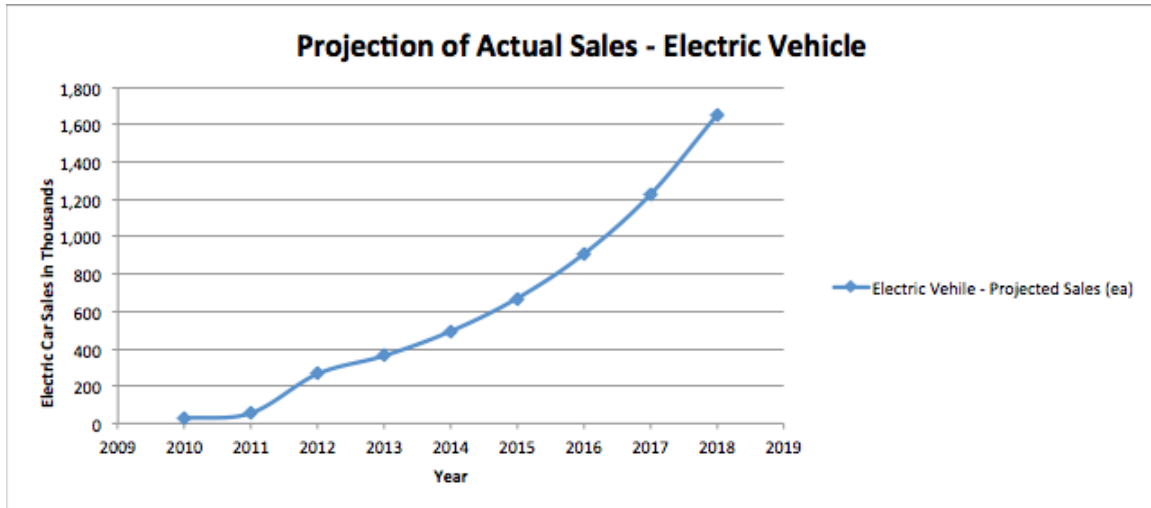


Figure 6. Predicted EV Sales for the Period 2011–2018 in Response to Taxation and Subsidy Policies as Projected by the Model

Figure 6 shows that electric vehicle sales will begin rising rapidly in a “hockey stick” manner once, the policies choices listed above are introduced in 2012. A rebate of \$15,000 to each EV buyer is expected to induce this “hockey stick” effect. In this scenario, the source of the rebate is the revenue generated from the gasoline excise tax.

Table 3 shows the annual excise taxes predicted to be collected each year through 2018, the amounts to be distributed as rebates for EV purchases, and the remaining sums to be used to implement other EV adoption policies (e.g., refunds to low-income families and recharge infrastructure build out incentives). Note that until 2017, the incentive rebates represent less than 25 percent of the collected tax.

Table 3. Excise Tax Collected

Year	Total Gasoline Excise Tax Collected	Tax Used For EV Rebates	Gas Tax Net of EV Rebate
2012	\$34,534,635,600	\$3,982,118,284	\$30,552,517,316
2013	\$68,548,941,078	\$5,438,617,192	\$63,110,323,885
2014	\$84,797,868,872	\$7,405,192,521	\$77,392,676,352
2015	\$83,588,354,094	\$10,054,056,083	\$73,534,298,011
2016	\$81,946,191,600	\$13,613,986,738	\$68,332,204,863
2017	\$79,722,573,766	\$18,388,609,526	\$61,333,964,241
2018	\$76,719,100,877	\$24,780,556,145	\$51,938,544,732

D. FORMULAIC SHORTCOMINGS

1. Use of Hybrid Coefficients

The coefficients for the EV model were transferred from the coefficients for the hybrid model, as there is insufficient historical data to solve for the EV model coefficients independently. However, in order to make that change, the cost of locomotion for EVs was adjusted to reflect the cost of electricity used to recharge EVs, versus the price of gasoline that influenced the cost of locomotion for the hybrid vehicle. That means that the EV predictive model is somewhat untethered from the cost of gasoline. The catchall coefficient may still capture the psychological influence of the price of gasoline, but the economic consequences are no longer directly a part of the EV predictive model. However, the economic effect of changes to the price of gasoline still impacts the predicted sales for SUVs (Eqn. 8). If that model were run to predict future sales, higher gasoline prices would result in fewer sales of SUVs, but, as constructed, the EV model may not sufficiently account for the positive influence on EV sales attributable to increases in the price of gasoline. The likely result is that the model under predicts the increase in EV sales as the price of gasoline increases.

2. The Model Does not Reflect the Bounded Nature of the Market

A fundamental reality, reflected in most in depth economic analyses, is that most markets are finite. Consequently, although the total vehicle market may experience year-to-year growth, the total number of vehicles sold in any year is finite. Thus, if a new make, model or entirely new type of vehicle is introduced, its sales volume generally

comes at the expense of another group or groups of vehicles. A detailed analysis that intended to predict sales volumes with accuracy and precision at all sales levels must account for this zero sum game. Unfortunately, such an analysis is exceptionally complex. It is beyond the scope and purpose of this work to develop a model of that complexity.

The EV predictive formula (Eqn. 9) does not assume a zero sum game. In other-words, there is no limit on the total sales of vehicles of all classes combined. Increased sales of EVs do not automatically result in the loss of sales for any other category of vehicles. While the factors that tend to increase EV sales are likely to decrease other vehicle sales if their predictive models were run with the same assumptions, there is a less than perfect link. Fortunately, when the sales volume of any group is small, its effect on the sales volume of other groups is negligibly small. Consequently, a model projecting its variation under the effects of certain market drivers can be decoupled from other groups without introducing an unduly large error. This was the underlying assumption for the Jehani and Sibdari (2010) model and is the basis for the model used herein.

The consequence of this assumption is that the model can be a good predictor of the onset of certain trends (e.g., the “bend” of a “hockey stick” type growth), which occurs while the sales volume is still small. It will fail to project the actual sales or their impact on other segments of the market (e.g., sales of gasoline), once those sales have grown to a level that is significant relative to the rest of the market. At the low end of the changes in sales, that is probably not significant, but it reinforces the premise, especially at higher volumes of sales, that the model is designed to demonstrate trends, movement and changes from various policy choices. It will identify the “hockey stick” turning point seen on the graph where the rate of sales dramatically increases. It is not intended to predict actual specific sales numbers.

3. Inherent Risks of Prediction

As mentioned previously, past performance is no guarantee of future success. The model is based on historical data of the effects of gasoline price increases and other

factors on consumer vehicle preference. Furthermore, there is no real world data to review an increase in the price of gasoline of the magnitude suggested herein. As gasoline prices reach high levels, other consequences will almost certainly emerge. For example, consumers may attempt to move closer to work and walk or bike, foregoing a motor vehicle all together. Though this would still diminish the nation's overall use of oil, it might also diminish EV sales.

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V. CONCLUSIONS

A. SUGGESTED COURSE OF ACTION

The modeling results demonstrate that it is possible to alter consumer behavior significantly in favor of EV purchases by using an excise tax to raise the price of gasoline and using those funds in part to bring down the cost of EVs. Each step in lowering the use of gasoline by automobiles is a step towards energy independence and greater national and homeland security. Therefore, in a program announced significantly ahead of time, the federal government should implement an excise tax on retail gasoline purchases. The funds raised should go directly towards a tax credit or point of purchase credit for the purchase of EVs. The additional funds raised should be used to offset the effect of the tax on the lowest income segment in the population. That concern is addressed in more detail later in this chapter. Additionally, it is important to use those funds as incentive to propel the creation of a recharging infrastructure in the United States. The ultimate goal is an all EV automobile market and the end of the internal combustion automobile engine, without diminishment of the U.S. driving experience.

1. Excise Tax on Retail Gasoline Purchases

A tax on the sale of retail gasoline should be implemented. As was demonstrated by the model, an excise tax of between two and five dollars raises more funds than is required for rebates, even where the rebate is \$15,000, double the current rebate on new EV purchases. In order to allow consumers to prepare for the economic consequences of the excise tax, and with the goal of seeing change at the beginning of implementation, it is important that the policy be announced ahead of time. It takes one to two years of gasoline price increases before there are real shifts in purchase behaviors (Goodwin, 2004; Jeihani & Sibdari, 2010).

Phasing in the tax serves two purposes. First, though announcing the increase ahead of time should allow for a more immediate response to the price increases, there are inevitably consumers who cannot or will not react immediately. A phase in allows some of those consumers to adjust before the full tax is in place. Additionally, a phase in

would allow any unanticipated consequences to occur in a more controlled manner, diminishing their magnitude and allowing more time to respond appropriately.

Eventually, economies of scale should bring down the price of EVs so that they are sufficiently competitive without government rebates. According to the DOE, just the creation of battery manufacturing plants, spurred by recovery act matching funds, is lowering battery prices through economies of scale (Stimulus, 2010). As demand increases and production rises to meet the demand, prices should fall allowing market forces to drive the price reductions.

2. Recharge Infrastructure

If EVs are to be adopted nationwide, a well-designed and widely distributed network of charging stations is imperative (Electric, 2010). A portion of the funds collected by the excise tax net of EV rebates should be used to assist in the creation of this infrastructure. Column four of Table 3 illustrates the additional monies that will be available to policymakers. A portion of those funds will be required to offset the economic hardship the gasoline tax may create for low-income families. That issue is discussed in more detail below.

Range anxiety is a phenomenon not present with hybrid vehicles and, therefore, not captured by the coefficients developed from hybrid vehicle historical data. Range anxiety is particularly troublesome because it is more than a reflection of the ability of a driver to go from point A to point B. It reflects that a driver may not try to go from point A to point B even when the EV is fully capable of traveling that distance. Bostford and Szczepanek describe this phenomenon well (2009). They describe range anxiety using an anecdote from the Tokyo Electric Power Company (TEPCO). In 2007, TEPCO introduced electric service vehicles and tracked employee usage of the vehicles over an 8 X 15 km service area. Initially, overnight charging was the only option. A few months into the program they realized that EV drivers were only covering a small portion of the service area. TEPCO responded by adding a fast charge station that could be used any time of the day. After its installation, EV drivers accessed the service area in a similar manner to conventional vehicle drivers. Most interestingly, the fast charger was rarely

used (Bostford & Szczepanek, 2009). The point is that the fast charger was not necessary to meet the actual needs of the EVs, it was necessary to meet the psychological needs of the EV drivers. It was necessary to counter range anxiety. If range anxiety is not addressed, it may have a significant deleterious effect on the accuracy of the EV model.

Fortunately, recent stimulus funds have established the efficacy of dollar for dollar grants in establishing a recharge infrastructure. As described previously, with two million dollars of stimulus funds Oregon has created a recharge infrastructure covering all of Interstate 5 that runs through the state. The facilities are spaced so that a driver is never more than 50 miles between recharge locations (Oregon, 2010). It is not expected that funds will be required to incentivize all recharge stations. As EV sales increase, market forces may lead to the development of the infrastructure as well. Already some retail establishments have determined that it is in their interest to put in recharge parking spaces (DeLong, 2011). Nevertheless, especially given the concerns of range anxiety, to truly jump start U.S. energy independence, significant investment should be put into creating a recharge infrastructure, paid for by the retail gasoline excise tax.

3. New Power Stations and Infrastructure

EVs use far more energy than may be obvious. In fact, adding an EV to a neighborhood, will increase the demand for electricity to the same or greater extent of adding a new house to the neighborhood. For example, the Tesla Roadster contains a 56 kWh battery (Roadster Innovations, n.d.) that allows the vehicle to go 245 miles on a single charge (Roadster Features, n.d.). By comparison, consumption by residential utility customers averaged 908 kWh per month (How, 2011), meaning that the average house uses about 30 kWh per day. The energy currently provided by gasoline will have to come from power stations. This means the U.S. will need additional stations but also additional transmission infrastructure as the current infrastructure is not sufficient (Electric, 2010; Lewis, 2010).

Fortunately, power companies are largely financially successful (Gilbert, 2010). If the regulatory obstacles are diminished, private industry should take over to build the generation and transmission capabilities to meet the demand created by EVs (Gold 2009);

however, it takes time to build power stations and the transmission infrastructure to support it. If the regulatory obstacles are removed, and the government's plan to encourage EV adoption is transparent, unambiguous, communicated and publicized one to two years before it goes into effect, that will allow market forces to begin responding so they are prepared to meet the rise in demand.

B. CRITICAL SECONDARY CONCERNS

1. Public Support Financially

Will the U.S. citizenry accept a substantial tax on the sale of gasoline? There is a historical basis to believe they might, if citizens accept the security implications that are alleviated by the tax. A parallel can be drawn to economic events during and after WWII. Between the purchase of government war bonds, and the substantial federal income tax paid by Americans, federal revenues were raised to never before seen amounts, "\$98.3 billion by 1945, nearly half the war-swollen GDP" (Sparrow, 2008). Though the government's propaganda campaign centered on the ethical imperative to counter the Axis tyranny, combined with the self-interest realized by investing in war bonds, research has shown that the government missed the mark. The real reason citizens accepted the fiscal hardships was not for abstract ideals, rather it was when people were faced with helping someone they could identify with (Sparrow, 2008). The idealized all-American GI, the boy next door, is who they were helping. By paying taxes and buying bonds, people saw themselves putting a gun and bullets directly in the hands of a GI. This allowed for a sort of indirect participation in the war itself (Sparrow, 2008).

A similar view of the same social/psychological phenomena has been referred to as the post-tragedy opportunity bubble (Breckenridge & Moghaddam, 2011). In their paper, Breckenridge and Moghaddam look at the psychological similarities between the attacks of 9/11 and the attack on Pearl Harbor (2011). They describe the fleeting moment of opportunity where the populace rallies around its leaders, trusts them more, and, because they are looking for a specific way to help, can be directed in a manner not usually possible (Breckenridge & Moghaddam, 2011).

In the first State of the Union Address after 9/11, President Bush called on Americans to give at least two years over the course of their lifetimes to the service of their neighbors and nation (Bush, 2002). Unfortunately, that message did not resonate with Americans in a way likely to make them feel like part of the fight against those who attacked us. The success of fiscal participation during WWII turned on personalizing the response, allowing the citizenry to feel it was truly participating in defeating the great evil. The urgent desire to participate was given outlet in a contemporaneous ability to aid in the defeat of the enemy. The outlet was immediate and direct, not an ephemeral and vague channeling of that desire to some general purpose, at some undetermined time in the future.

In reviewing the post 9/11 response, Breckenridge and Moghaddam (2011) show that the government's failure to provide meaningful participation resulted in a failure to capture the public's long-term engagement and support. There was no mechanism for the citizenry to help defeat the great evil. Furthermore, the opportunity to harness the public sentiment is fleeting. Once the bubble pops, the opportunity is essentially lost (Breckenridge & Moghaddam, 2011).

Taken together, these examples show an uphill, though not impossible, task of moving the citizenry of the United States to accept the sacrifice of a significant tax on gasoline. A simple and straightforward message needs to make the case that there is an ongoing and real evil threatening the nation, caused by dependence on foreign oil. In countering this threat, the link must be clear in the minds of the citizenry; money spent at the pump is buying back the very guns and bombs that are killing Americans. Secondly, a personal and clear image must be established between the money paid and the lives saved. While paying the tax may not put a gun in the hand of a GI, it can be shown to take a gun out of the hands of the enemy. No more traumatic head injuries, no more amputees, no more sophisticated plots to attack America.

Right now the country may not be ready to view the threat of dependence on foreign oil in the same concrete terms as the bombing of Pearl Harbor or the events of 9/11. If that is the case, the government should nonetheless begin building the framework. With so many enemies funded by oil sales, it is unfortunately only a matter

of time before another tragic event disrupts the landscape of the United States. When that happens, leadership should be ready to ask for the participation of the citizenry, to ask for their shared sacrifice as a direct and meaningful way to participate in defeating those who seek to do us harm.

2. Public Support Politically

By using EVs as the mechanism to end energy dependence, this thesis promotes a solution that both the political right (energy dependence) and the political left (EVs) have vocally supported in the past. Though this paper is solely focused on the detrimental effects energy dependence has on U.S. security, proposing a solution that is agreeable to both sides of the political spectrum should ease adoption by the political system that must choose whether or not and how to implement the plan.

3. Source of Energy Storage Materials

The current technology of choice for powering EVs is the lithium ion battery (Forero, 2010; Tahil, 2006). There are several problems with reliance on lithium for energy storage. In the first instance, there is disagreement with just how much economically available lithium there is in the world, with some experts saying supplies are quite limited (Tahil, 2006; Meridian, 2008) and others saying there is quite a bit available (Evans, 2008). More troubling for national and homeland security is the location of the largest known deposits of lithium. They are not in the United States. The Andes Mountains in South America, specifically the area where the borders of Chile, Bolivia and Argentina meet, contain a large majority of the world's usable lithium (Forero, 2010; Meridian, 2008), with Bolivia containing the largest known deposits in the world (Risen, 2010). Recent discoveries in Afghanistan suggest that it too may possess significant deposits of lithium (Risen, 2010). Additionally, current battery technology relies on magnets of a type that depends on rare earth metals like neodymium, 95 percent of which are produced in China (Ramsey, 2011).

It defeats the goal of energy independence if the U.S. simply trades one energy dependency for another. As has been said, "We know that Bolivia can become the Saudi Arabia of Lithium" (Romero, 2009). Policymakers must be mindful of this potential

development, but there are reasons to believe it is avoidable. In the first instance, unlike reliance on oil, where the resource is consumed with each trip, with EVs, locally produced electricity is consumed with each trip where additional lithium is only required when the battery is replaced or a new vehicle is purchased.

There are also other potential sources of lithium. The Institute of Ocean Energy at Saga University in Japan has described the research being conducted by Japan and South Korea to enable harvesting of the 230 billion tons of lithium present in seawater (Institute, n.d.).

Finally, there is reason to believe that lithium may not be the one and only source of energy for EV batteries. The history of the EV battery shows a progression every few years to a different source material (Chan, 2004). EV batteries have gone from predominantly lead acid to nickel metal hydride and now to lithium-ion (Chan, 2004). Development is constantly progressing on a variety of alternatives like aluminum air batteries. Some research has shown reason to believe that metal air batteries—where the cathode of the battery is air—could provide up to 11 times the energy density of the best lithium-ion batteries currently available (Hamilton, 2009). Variety should be strongly encouraged, with appropriate nudges (Thaler, 2008) to help orient the market’s focus towards resources available within the U.S.

C. UNINTENDED CONSEQUENCES AND SECONDARY CONCERNS

1. Fungible Nature of the Oil Market

As described earlier in this thesis, oil is part of a fungible world market (Chairman, 2007). That means that reducing oil to levels where the United States is capable of providing all its petroleum needs, does not necessarily mean that the oil used in the United States will be 100 percent domestically produced. As it stands currently, the United States exports two million barrels of oil per day (EIA, 2010a, p. 128). As U.S. demand decreases with the roll out of EVs, the U.S. may begin to export more of its oil. As a fungible product, domestic oil prices will not necessarily be protected from the effects of international disruption of oil supplies. However, if the United States is

capable of supplying its own oil requirements, then with proper planning it can ensure a relatively uninterrupted supply of oil regardless of international supply disruptions.

For example, in considering what first responders can do in the event of localized fuel shortages, it has been suggested that they should enter into firm contracts for fuel (Leotta, 2006). At present, firm contracts would not solve the problem for the country as a whole. If the world supply were disrupted, domestic sources could not fulfill the contracts, because there simply would not be enough fuel to go around. However, once energy independence is achieved, firm contracts with domestic suppliers could all be fulfilled. Those portions of the government or private sector who wish to hedge against supply disruptions could enter into futures contracts, or other contractual arrangements to ensure a given supply at a given price.

2. A Regressive Excise Tax

A tax is regressive when it causes lower-income families to pay a higher percentage of their income to the tax (Internal Revenue Service, n.d.). By adding a cost per gallon of gasoline, the financial impact could have a disproportionate impact on lower-income families. A simple way to lessen the impact would be in the form of a tax credit that is phased out over a particular income level. To avoid bureaucratic expenses, a national or regional average of both the price of gasoline and of the average gallons consumed can be used. The credit will not precisely match the expense incurred, but can be sufficiently harmonized to minimize the harm to lower-income families.

For example, in 2009, there were 8.8 million families living below the poverty line. For an idea of what that measures for a family of four, made up of two adults and two children, the poverty line was \$21,756 (DeNavas-Walt, 2010). For purposes of this example, assume that each of those families had one vehicle. As explained in Chapter IV, the average driver uses 490 gallons of gasoline a year. Assuming policymakers felt that all families below the poverty line should receive a rebate then in a year where the gasoline excise tax was two dollars, 8.8 million families would receive a rebate of \$980. That would be a total rebate to those families of \$8.624 billion. If the rebate was phased out incrementally for families above the poverty line, even assuming another \$8.624

billion was returned to those families, Table 3 shows that there would still be \$13.3 billion left to use to promote recharge infrastructure growth (\$30.55 billion left after EV rebates, minus \$8.624 billion times two).

3. Risk Increasing Cost of Goods / Inflation

Recent gasoline price increases have caused a corresponding increase in the cost of goods, and may diminish consumers' savings (CBO, 2008; Republican, 2010). Rising gasoline prices can contribute to higher transportation costs, thereby raising expenses at all stages of production (Republican, 2010). The proposed course of action in this thesis minimizes that threat in a number of ways. In the first instance, the excise fee is only levied on motor fuel. This does not include diesel fuel. In 2009, in the U.S., there was approximately 16,878,000 gallons of diesel fuel sold per day (EIA, n.d. b) compared to approximately 49,798,000 gallons of retail unleaded gasoline sold per day (EIA, n.d. a). Furthermore, the 49,798,000 gallons of retail gasoline subject to the excise tax is only about one sixth of the motor gasoline sales each day. The other categories of motor gasoline sold each day are DTW, rack, and bulk (EIA, n.d. a). Therefore, governments and businesses that obtain their gasoline in bulk would not be subject to the excise tax under the implementation proposed in this thesis.

4. Significant Drop in the Price of Oil

The program may also be a victim of its own success. With sufficient numbers of EVs on the roads, the demand for gasoline will take a measurable decline. Should a sufficient number of other nations follow a similar course, the worldwide demand for gasoline may drop significantly, thereby reducing the price of oil. As the price of oil and therefore gasoline drops, the effect of the program may also decline. This can be remedied by determining an appropriate floor for the price of gasoline and automatically increasing the excise fee to maintain that floor.

D. FOLLOW-ON RESEARCH

1. A More Complex Version of the Present Model

Any number of factors can be added to the model. As long as there is historical data measuring a particular factor, limitless terms can be added to the equation and the coefficients solved for anew, using a least squares mean approach. For example, it would be possible to separate out gasoline price as its own variable rather than simply have it wrapped up in vehicle fuel efficiency. As part of fuel efficiency, it is really an economic view of the relationship of gasoline price to vehicle choice. To the extent there is a psychological impact from gasoline price and to allow gasoline effects to be more specifically accounted for in the model, gasoline price could be included as an independent factor. Though this psychological factor should be included in the catchall term for the hybrid, and, therefore for the electric, vehicles, it may be possible to capture the effect more directly. If a more complex model were developed for hybrid vehicles, and the terms included appeared logically connected to the sale of EVs, then the more complex model could be used, adopting the hybrid vehicle coefficients, to predict future EV sales.

2. A More Complex Modeling System

One of the earlier described limits on the predictive model used in this thesis is that the model is unbounded. In other-words, it does not envision a world where vehicle purchases are essentially a zero sum game; however, the real world is essentially bounded. The vast majority of consumers cannot purchase an EV and a gas-powered vehicle. In the main, when it is time to go new car shopping, buyers are in the market to purchase a single vehicle. This break with the reality of the marketplace means that predictions of sales, especially at large volumes, develop obvious inaccuracies. If run far enough into the future, the model will eventually predict sales of EVs that exceeds any reasonable expectation of total vehicle sales for that year. It may be possible to create a model that incorporates the linear relationship concept presented here, but that does so in a way that bounds the universe of total vehicle sales.

3. Determine Coefficients for EVs Independently

As time marches forward and EV sales become a reality of the marketplace, it may be possible to solve for the coefficients in the EV formula independently, rather than borrowing from the hybrid equation. In the present model, there are five coefficients. That means that there must be a minimum of five years of data in order to solve for the coefficients. Once it is possible to do so, it should lead to an even more accurate EV model.

4. Determining the Cost of Energy Dependence

Though the ramifications of energy dependence were discussed at great length, this thesis did not attempt to put a dollar figure on the nation's reliance on foreign oil. Certainly the oil trade deficit is described in dollars, but the actual cost of securing the flow of oil and of other policy choices the nation makes due to its dependence have not been determined. Doing so may provide additional understanding to support policy choices. If the cost were determined and then averaged over the various uses of that oil, the true cost of oil being consumed could be established.

5. Infrastructure Questions

Though it is clear that additional recharge infrastructure is needed, and this thesis suggests that monies raised from the excise tax should be used to spur the creation of the infrastructure, further research would be helpful. It would be useful to determine the ideal recharge locations to achieve the best bang for the buck. It would be useful to study range anxiety so the recharge infrastructure met the psychological needs of consumers, not just the physical needs of the EVs.

Similarly, it is clear that additional power generation will be required to meet the increased demands on electricity from the growth of the EV market. Precisely how much and where remains to be determined. Some of the demand may be met without increasing actual power plant production. For example, smart meters that encourage non-

peak time charging can be installed. Some households might recharge using their own solar or wind micro power generators. Whatever the need, it will be better met if it is studied and well planned, rather than done haphazardly.

E. CONCLUSION

For 40 years, every president of the United States has proclaimed the critical importance of energy independence. Time and again, the chains of foreign oil have shackled the decisions of American officials; yet, nothing has been done. No pragmatic, realistic step-by-step plan has been pursued to end this scourge on the American people. This thesis proscribes the means whereby America can break free of those artificially imposed restraints. There is a cost to achieving energy independence, and as shown herein, that cost is two to five dollars on each gallon of retail gasoline sold. With conviction, determination and selfless leadership, the United States can achieve energy independence in a few short years.

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