The Effectiveness of Plug-In Hybrid Electric Vehicles in Reducing the Demand for Gasoline

A case for oil independence through the modification of the light vehicle fleet

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Table of Content

Abstract

97% of the energy consumed by light vehicle fleet in the USA, is gasoline derived from oil. This re-iterates how susceptible the US is to fluctuations in the price of oil and thus gasoline. Utilizing a static simulation and dynamic econometric models the paper attempts to estimate the effective change in demand for gasoline resulting from the conversion of the fleet from Internal Combustion Engine Vehicles (ICVs) to PHEVs as they are brought to market. The conversion of the fleet over a 15 year period could allow the US to become oil independent from foreign unfriendly suppliers.

Introduction

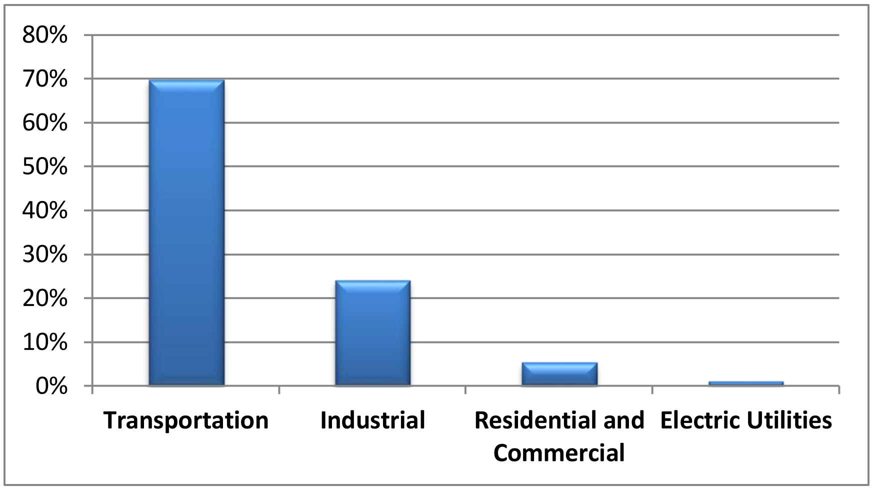
The United States of America consumes 24% of all oil and petroleum produced in the world, while producing a little over 6% of total world output. Gasoline, as a derivative of oil, accounts for 97% of the energy inputs used in the mobility of labor and capital. This demand has continued to grow unabated into the 21st century. The US transportation sector currently consumes approximately 19.5 million barrels per day (mbpd) (71% - 2010). 90% of the barrels of oil are processed into petroleum and other petroleum products. 71% of this petroleum is then used in the transportation sector where 49% is consumed as finished petroleum fuel (gasoline) powering conventional private passenger vehicles. This equates to 6.1 mbpd used by households to power their vehicles! In 2010, the US imported approximately 11.8 mbpd from foreign sources, where 6.7 mbpd (58%) were from unstable, undemocratic regions. This brief overview simply illustrates that around 49% of all oil imported and consumed within the US is in fact used in our vehicles as gasoline. Modifying the automobile to utilize an alternative fuel namely electricity, in this case a Plug-In Hybrid Electric Vehicle (PHEV), is assumed to have little to no negative externalities on consumers as the safety and driving habits resulting from the switch should remain unaffected. There are a number of benefits to this transformation, which will be reviewed in the following pages. This paper attempts to estimate the effective change in demand for gasoline resulting from the conversion of the light vehicle fleet from Internal Combustion Engine Vehicles (ICVs) to PHEVs as they are brought to market.

The first section of this paper will put forward the methodological approach undertaken in the research to estimate the change in demand for gasoline. A theoretical and static simulation model will be used to simulate the effects of PHEVs on gasoline demand as well as the effect on household incomes. The vehicle technology of a Plug-In Hybrid Electric Vehicle was used as the AFV of choice due to the ease of adoptability without requiring any significant change in driving habits, relatively low cost, market readiness and the capacity to meet household demand without requiring additional infrastructural development. A literature review of established research will be performed to shed further light on the significance of oil dependence, gasoline elasticity of demand, pricing implications of oil and gasoline, market structures and the role they play. The fourth section of the paper will describe the data used and variables incorporated in the dynamic econometric models used in this paper. The fifth section will present the empirical results from the dynamic model and give a brief description into what these results imply. The final segment will extrapolate, from a theoretical perspective; the effects on gasoline demand from the simulated models' results, both static and dynamic and will elaborate on any policy initiatives government can undertake.

Methodology: Theoretical and Static Simulation models

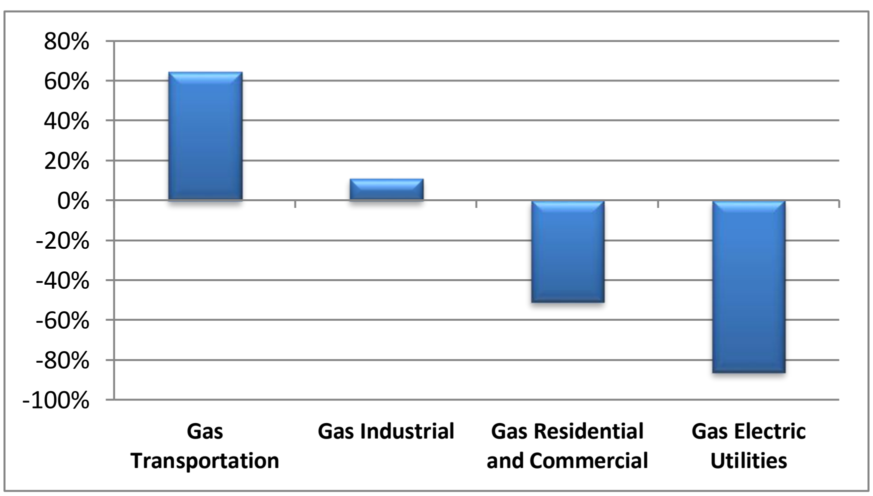
As stated in the introduction, the US is dangerously dependent on oil as a source of energy that effectively allows for the mobility of factors of production – Labor and Capital. This dependence is almost entirely centralized in the transportation sector. (see Graph 1 below)

Graph 1: United States Petroleum Consumption, 2010



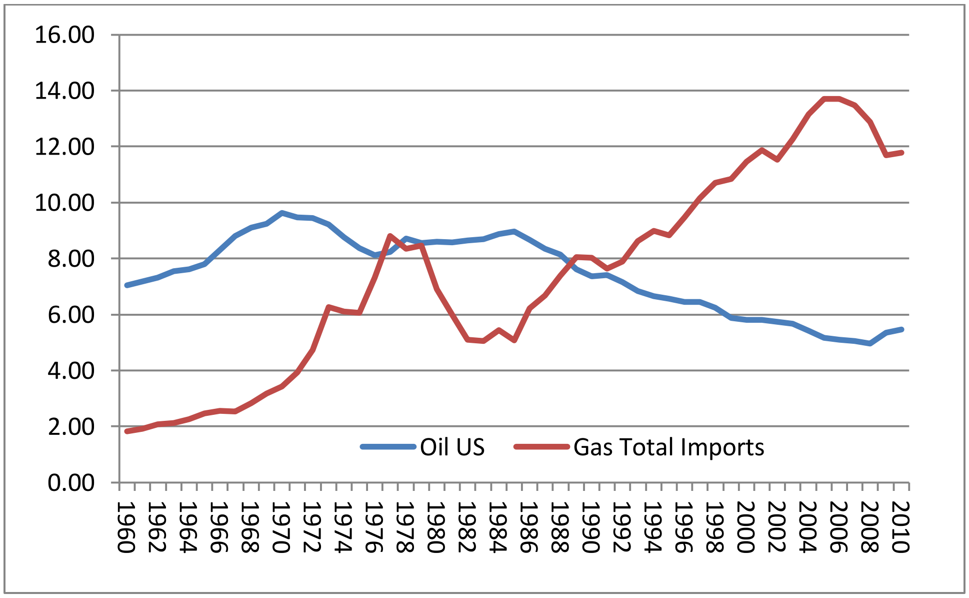
97% of the energy consumed by light vehicle transportation, passenger cars and small trucks, is gasoline derived from oil. This statistic elucidates the severity of the situation and how susceptible the US is to fluctuations in the price of oil and thus gasoline, as further shown in the paper by Greene et al (1998). During the period from 1973 to 2010 the use of petroleum products in the transportation sector grew by 64% (174% from 1960) while the other three sectors showed negative to minimal growth in usage. (See graph 2 below) This further validates the reasoning why the US should focus its attention on the Transportation sector to reduce oil consumption,

Graph 2: Growth in Gasoline Consumption, 1960 to 2010



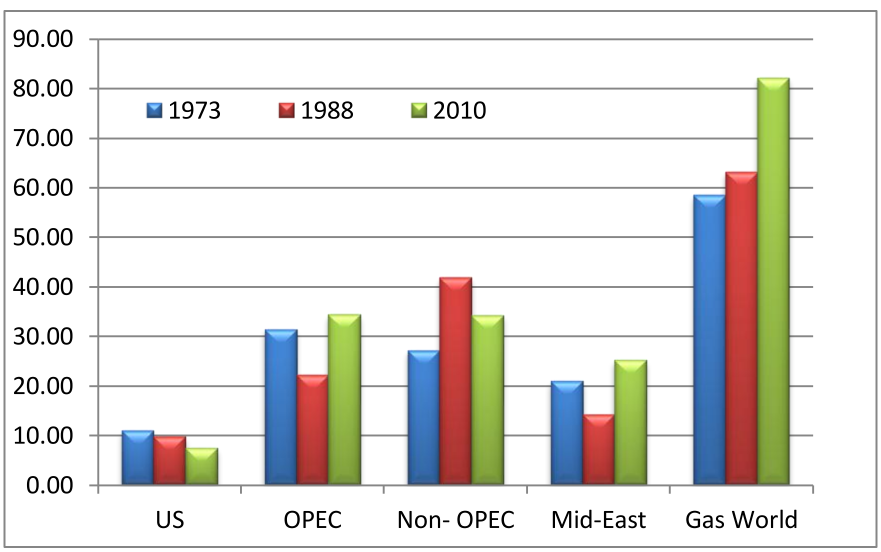
Of the 246 million cars on the road, only 695,000 are AFV, which accounts for 0.28% of all vehicles on the road. This implies that 99.7% of every car on the road today is completely reliant on a fuel source that is extremely susceptible to supply disruptions and controlled by some of the most ruthless regimes on the planet. In fact, around 69% of all petroleum produced on the planet is produced by countries which have a blatant disregard for human rights and democratic values. These are the same countries that exude control over one of the most important inputs allowing a country to function as an economic state, the power of mobility. There are many who believe the gravest problem facing our generation is that of global warming and feel that we need to alleviate the use of oil in our electrical generation to curb our greenhouse gas emissions. This statement is not entirely accurate, as is portrayed by the graph 2 above. It is not enough to simply switch to renewable energy to reduce our reliance on oil thereby reducing our emissions. In fact, less than 3% of our electrical energy is generated from oil. A 100% switch to renewable energy (wind, solar etc) would have little to no effect on emissions, produced from consuming oil, and oil dependence. Global warming is a very real and present danger; it is however, a long term threat. It is assumed that consumers - households and businesses (as well as some politicians) - have a very short term outlook in their decision making process. That being said, this paper proposes to develop a new format to build a case for AFVs, and in particular PHEV, through simulating the oil savings resulting from the transformation of the light vehicle fleet. If sufficient emphasis is placed on national security and alleviating the US's dependence on oil, a much higher success rate at generating awareness and sought after demand could be realized, due to the 'close-to-home' and short term nature of the issue.

Graph 3: Oil Imports Vs Domestic Production



The graph above, illustrates how the future relationship of oil and the US is in dire need of significant transformation. Current production levels in the US have been in constant decline since the 1960s, on decreasing by approximately 30%. During this same period, oil imports rose steadily by a rate of 546%, of which OPEC accounted for 42% of these imports.

Graph 4: Petroleum Production

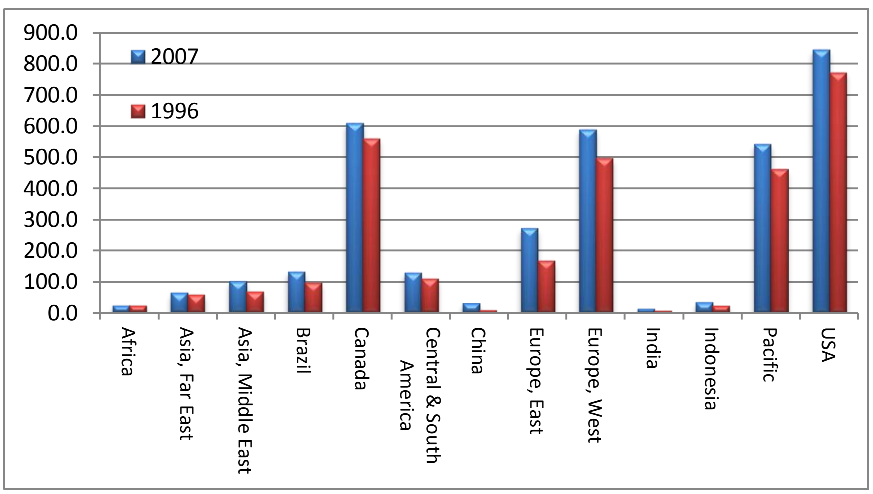


The graph to the left indicates that the US, even though its unquenchable thirst for oil continues to grow, is producing fewer barrels of petroleum each year. Very few new oil reserves are being discovered and those that are, prove very costly to extract. Refining capacity has not increased domestically either, which further exasperates the problem of the US becoming more susceptible to fluctuations in oil supply and prices.

It would seem that the biggest hurdle to the transformation is creating sufficient awareness of the importance of oil independence onto the consumer and average household. An effective shift in the reliance on oil must come from the household and general population, essentially from the ground up. The one hundred and sixteen million households across American that make the decisions each day on what car to drive, where to eat and what to spend their income on, need to be made aware of the dire ramifications that could befall them, if one of the unstable regions of the world withheld supply even for a few weeks. These consumers need to be given options to remain mobile; right now there is none in mass production. The impetus placed on the transportation sector is not unfounded as over 70% of all oil consumed in the US is used in the transportation sector, as shown in graph 2 above.

The transportation sector in the US is dominated by the household consumer to the point that on average there are 844 vehicles per 1000 people. This is significantly higher than most other industrialized nations as shown in the graph below:

Graph 5: Vehicles per Thousand People, 2007 & 1996



This graph expresses two vital pieces of information. First, the household vehicle consumer is the key to solving this problematic issue on the overall dependence on oil. Secondly, two of the world's largest countries, from a per capita standpoint, China and India barely register on the graph, while their populations account for 40% of the total global population to date. This is a startling glimpse into how much pressure will be asserted on supply and prices once these sleeping giants awake and their demand begins to grow. It is but a matter of time.

This paper will first quantify the effects on demand for gasoline as more PHEV are sent to market. The initial simulation as shown in Table 1 below, is a simplification of household behavior and gasoline demand where it is assumed household characteristics and other relevant economic market factors (energy prices, substitution effects, incomes, preferences, government policy, vehicle characteristics, driving habits, employment, infrastructure) where held fixed, *cetris paribus.* This allowed for a snapshot estimation into the value of both gallons of gasoline and US dollars that could be saved resulting from the transformation from ICVs to PHEVs. As former CIA Director, James Woolsey, once said, "*A plug-in hybrid vehicle (PHEV) is an electric car with an insurance policy - a gas engine*". The technology and vehicle simply make sense! The greatest obstacle to the average household purchasing a pure Electric Vehicle (EV) was primarily that of range, most EVs can only go 100 to 250 miles before needing a re-charge which can then take anywhere from 6 to 8 hours. The lack of mobility and flexibility in quick re-charge has made consumers apprehensive as they need something that can fit into their daily lives. A PHEV does just that, it allows the driver to travel on pure electricity anywhere from 20 to 60 miles before the gasoline engine takes over and operates as a regular ICV. In essence it is the ultimate hybrid. The Argonne institute (2005) presented in their research that, on average, a household will drive around 60km (32miles), while Huntington (2009) found using his 1 day travel survey of California that on average more than 80% of Californians drive less than 20 miles per day. Using the U.S. Department of Transportation's Nationwide Personal Transportation Survey, average daily Miles Traveled (MT) were calculated (see table 1A). On average, a household drives around 18.1 vehicle miles per day. In fact, the only time a trip was above the 20 mile point (as accounted for by the NHTS survey - see appendix table 2A) was for vacations taken which only accounted for 1.8% of total miles driven. The Electric Power Research Institute (EPRI - 2005) calculated that, on average, a household could reduce fuel usage by an estimated 60% and where the cost of powering the vehicle with electricity would realize a gas equivalent price of $0.75 per gallon. With data gathered from various sources, an average MPG for a PHEV was ascertained from current PHEV driver surveys given their daily driving habits, electric drive capability and re-charge frequency. An average of 105 MPG was estimated on a PHEV20 conversion, implying that the first 20 miles would be driven on pure electricity, while the remaining MT would achieve an ICV mileage of 22.5 MPG. A combination of these MPGs allowed the drivers to compute the 105 MPG. It is not uncommon to actually reach 150+ MPG when a PHEV40 or even PHEV60 is driven.

To attempt to place a monetary value on the displacement of oil resulting from the conversion of the current vehicle fleet to PHEV, a fixed-Static simulation model was estimated with four different conversion scenarios, 100%, 75%, 50% and 25%.

Simulation of PHEV Oil Displacement Effect

HOUSEHOLD AND VEHICLE DATA		Converted Vehicles ('000s)	Total Conversion	15 year period
			(US$ million)	
	Total Vehicles on the Road ('000s)	250,000	$3,750,000	$250,000
	- Optimistic - 75% Penetration	187,500	$2,812,500	
	- Neutral - 50% Penetration	125,000	$1,875,000	
	- Pessimistic - 25% Penetration	62,500	$937,500	
	Cost of Conversion (cetris paribus) per Vehice *(Fair market value)*	$15,000	16,667	*Cars converted per year*
	Total Number of Households, US ('000)	116,011		
	Total VMT, 2010 (Million)	2,947,000		
ENERGY | OIL		**Million Barrels/day**	**Million Barrels/year**	**Gallons (Million) per day**
	US Oil Consumption Total (2010)	19.40	7,081	815
	US Oil Imports, 2010	11.79	4,304	495
	US Oil Imports from Unfriendly Nations, 2010	7.72	2,817	*65%*
	US Oil Imports from American Conts., 2010	4.08	1,487	*35%*
	US($) per BBLS Standard Crude Oil, 2010	**$111**		
	Pice per Gallon of Gasoline, 2010	**$3.50**		
CONSUMPTION | GASOLINE		**Conventional IC Vehicle**	**Converted PHEV**	**Fleet Conversion**
	MPG	22.6	105	
	Gallons of Gasoline Consumed, per Vehicle, per year	522	112	
	Gallons of Gasoline Consumed, per Vehicle, per day	1.43	0.31	**1.12**
	Gasoline Purchased per Vehicle/Year (US$)	$1,827	$393	$1,434
	Total Gasoline Purchased (Million US$ per year)	$456,750	$98,233	$358,517
	% Share	100.0%	21.5%	78.5%
	Gas Displacement due to Conversion (millions of gallons/Yr)	**Remaining ICV Usage**	**PHEV Gas Usage**	**Gasoline Displaced**
	- Optimistic - 75% Penetration	32,625	21,050	**76,825**
	- Neutral - 50% Penetration	65,250	14,033	**51,217**
	- Pessimistic - 25% Penetration	97,875	7,017	**25,608**
FUEL SAVINGS	**Displacement Valuation**	**Fuel Savings Value (US$ Millions)**	**Household Savings per Year**	**Savings after Electric re-charge cost**
	- Complete - 100% Penetration	$358,517	$3,090	**$2,915**
	- Optimistic - 75% Penetration	$268,888	$2,318	**$2,143**
	- Neutral - 50% Penetration	$179,258	$1,545	**$1,370**
	- Pessimistic - 25% Penetration	$89,629	$773	**$623**
OIL DISPLACEMENT	**Annual penetration**	**Millions of Barrels**	**% of Total Imports**	**Oil Savings (US$ Millions)**
	- Complete - 100% Penetration	2,439	57%	**$270,717**
	- Optimistic - 75% Penetration	1,829	43%	**$203,038**
	- Neutral - 50% Penetration	1,219	28%	**$135,358**
	- Pessimistic - 25% Penetration	610	14%	**$67,679**

The fixed-static simulation model above (Table 1) estimated the impact of PHEV in displacing gasoline as a primary energy source -- holding all household characteristics and other relevant economic factors fixed -- *cetris paribus,* under four different conversion scenarios. From the above analysis it is apparent that on average, a household can potentially save around $3,000 per year in fuel savings from switching to a PHEV, adjusting for an electricity re-charge cost of $175 annually (Duvall, 2005). One of the most remarkable benefits derived from this entire exercise is that if the US were to convert its entire light vehicle fleet (250 million vehicles) to PHEV, *cetris paribus,* we would see, on average, a decrease in oil usage of 2.4 billion barrels per year (6.7 mbpd), which equates to 57% of all oil currently being imported. In essence, the US could become completely independent of oil imports from undemocratic regimes and can simply import what is needed from Canada and other friendly nations, even as demand continued to grow. This would result in an estimated savings of $270 billion dollars per year! The reason this is set out over a 15 year period is primarily that, on average, the entire vehicle fleet in the US is renewed every 15 years (Sandalow, 2008) It was projected that at the current cost of conversion, $15,000 (battery cost, battery management system infrastructure, electric drive train and other smaller components and labor) the total cost per year would be $250 billion. With mass production, learning by doing and economies of scale setting in, we expect this cost to drastically decrease overtime. It is not expected that this cost of conversion should be entirely funded by the government, but could be split in a predetermined ratio between consumer, producers and government. Subsidies can be issued either directly to the consumer in a rebate check, or tax write-off or passed on through a production subsidy to the producer. Note, however, that this is not entirely a one way street; as for every ICV that is converted, additional oil savings will trickle back through the economy as increased disposable income, therefore enhancing the purchasing power of every driver adopting a PHEV.

The reduction in demand by the largest oil consuming nation in the world will also have serious ramifications on the price of a barrel of crude oil, further reducing this burden through import cost reductions. The US will significantly cut back on its oil import expenses to the amount of $270 billion per year once the entire fleet is converted. Additional sales tax revenue will be generated through stimulated demand which is assumed to offset the loss in tax revenue from gasoline purchases. The economy will be further stimulated by the creation of employment opportunities in this new emerging industry.

The second empirical estimation will utilize dynamic regression analysis within an Ordinary Least Squares (OLS) model structure with robust standard errors. This model will simulate the effect on gasoline demand from adoption of PHEVs if some or all of the fixed variables pertaining to household characteristics and relevant market factors were to change. These empirical assessments will grant the ability to determine the effect on the overall demand for oil (oil imports) from the modification of the vehicle fleet. A monetary value shall be attached to gauge the significance, and to warrant any policy reaction.

Literature Review

One of the first papers reviewed, entitled 'The outlook for US Oil Dependence' (Greene *et al*, 1998*),* illustrates the USA's level of dependence on oil and how vulnerable it is to manipulation of oil supply and prices by oil producing countries. This paper sets the stage for building a case for why the US needs to gain independence from oil. Greene, *et al* (1998) assessed the fundamental factors that lead to oil price shocks such as market power concentration (Cartels), inelastic demand behavior of consumers, supply manipulation and long run growth in demand. Secondly, the authors examined the economic effects of price shocks on oil-importing nations, reviewed for the past 25 years. A simulation of the global oil market and price effects on the US economy resulting from possible future oil supply disruptions and price spikes was undertaken. Weakness in this paper was found through the lack of any concrete empirical analysis to justify any specific relationships between the variables in question. The authors did however; make good use of existing literature to create a basis for their research. Green, *et al* (1998) deduced that US oil independence is primarily the result of short-run inelasticity of demand, monopoly power over supply and the reliance on oil imports. The authors went on to debunk the theory that oil dependence had waned over the past 25 years, they showed that it had increased substantially and was actually continuing to rise, as is the case of the centralized control over the market and supply by OPEC. Finally, the authors pointed out that the transportation sector in the US, which showed consumption of 80% of high-valued light crude oil currently imported, seems to be the most attractive source of reducing demand for oil imports. It is this final reference by the authors as well as the effectiveness of the paper conveying the urgency in a monetary framework, which will aid me in my research.

Honarvar (2009), estimated the asymmetric relationship between oil price movements and the price for gasoline in the United States. This paper shows how an increase in the price of gasoline is more sensitive to an increase in the price of oil than to a decrease. This results in a constant increase in gasoline prices over time. This unequivocally is one of the most compelling studies to date into the asymmetric relationship between retail gasoline and oil prices. The author initially set out to examine all existing empirical literature into this asymmetric relationship. Then a hidden cointegration approach was adopted to assess this relationship. The author examined the logarithmic transformation of the original data to assess whether the data series has a unit root by utilizing the augmented Dicky-Fuller test. The paper shed light on the behavior of oil and gasoline markets and indicated that shocks in oil markets can, in fact, induce a decrease in demand in the long run resulting from advancements in more efficient technologies, PHEVs. Honarvar (2009) showed that OPEC may not be able to effect change in long-run gasoline markets but does play a significant role in short-run gasoline prices. The author found an asymmetric relationship between gasoline and oil prices where the movements in price exhibited a long-run cointegrated relationship. The asymmetry can be attributed to consumer demand for more energy efficient technologies, such as AFVs, further justifying the need for this technology.

Huntington (2009), assessed the short and long-run adjustments in petroleum consumption within the US to energy price changes while carefully considering energy consumption decisions. These two papers (Honarvar and Huntington) simultaneously work towards justifying my proposed research in creating a case for PHEVs. The fact that the principal petroleum product for private vehicles is gasoline led Huntington to evaluate the short and long term adjustments in the price and demand for gasoline resulting from changes in energy prices, primarily that of oil. Huntington used a general dynamic framework within his regression analysis with both current and lagged values for petroleum demand and other independent variables. One of the strengths of the paper is its in-depth analysis of the price of gasoline and consumer demand for the good. This was undertaken using a 'price band' where the author assessed how long run prices were affected by short-run fluctuations in price above and below these critical ranges. The problem I found with the paper was the decomposition and equal weighting of petroleum products, which were used as different variables in the regression. More emphasis should have been placed on petroleum (gasoline) as an energy source as the other derivatives realistically only make up around 10 to 15% of oil consumed. Huntington (2009) concluded that the long-run effects of a change in the price of oil are much more significant than that of short-run effects. The author further explains how the long-run response to oil consumption is closely aligned to a country's turnover of capital stock (cars). The fundamental finding of this paper is that long-run price effects are stronger and more permanent when the price of oil surpasses a specific level. This offers new insight into the asymmetric relationship between changes in gasoline prices (below the maximum) resulting from changes in oil consumption. An issue I found troubling was the lack of attention placed on the supply-side of oil production and the manipulation of oil prices through market power. However, this paper does offer invaluable insight into the ever-present relationship between oil consumption and gasoline prices and the elasticity of demand for gasoline.

The fourth paper under review assessed the potential impact of the adoption of PHEV on energy demand and estimated gasoline and electricity demand for California. (Kang, J. E. *et al*, 2009, 541-556) This paper evaluated the substitution of PHEV's into the transportation sector and estimated their effect on the daily driving habits of individuals utilizing 1-day activity and travel diaries based on the 2000–2001 California Statewide Household Travel Survey. Four different charging scenarios and two different PHEV technologies were incorporated. The assessment is based on real vehicles and driving activities of households. (Kang, J. E. *et al*, 2009, 541-556). The authors simulated the potential energy and emission reduction from the adoption of PHEV to replace conventional ICV. It was expressed by the author, though findings were from several other studies reviewed, that the overall impact on electricity demand from charging PHEV would not exceed current available supply, even at a 100% penetration level. The authors' estimation of potential energy consumption by PHEVs replacing ICVs aided in further debunking the 'tail pipe to smoke stack' myth that, "*the energy consumed and emissions from ICV exhausts will be replaced by the significant increase in electrical energy consumed and emissions from power plants producing said electricity".* More attention was warranted to estimate the effect on gasoline from this substitution; however, the assessments made by the author into the driving habits of households will be of benefit in my attempt at understanding the demand determinants of a gallon of gasoline and the role PHEV will play at reducing this demand.

The analysis undertaken in the paper put forward by the Argonne Research Institute entitled, 'Plug-In Hybrid Electric Vehicles - How does one determine their Potential for Reducing U.S. Oil Dependence?' aimed to estimate the potential fuel saved per kWh of battery pack installed in PHEV and to compute the total national oil savings on the basis of total kWh of battery pack capacity sold in PHEV's. (Vyas, A. *et al*, 2001) The research approach set out by the authors was a highly involved technical analysis into both the chemical structure of the batteries as well as a cost comparison utilizing future present value determination of PHEVs, ICVs and HEVs. This allowed the authors to estimate the average fuel savings over time by households if the switch were made. The authors did not infer any monetary value to oil savings derived from the adoption of PHEVs into the marketplace. The paper will serve as a basis for understanding the different chemistries and drive trains available for PHEV and how these will impact the overall cost of the vehicle (battery pack) and thus the fuel savings generated. Households characteristics presented in the paper will also play a pivotal role in establishing the demand determinants of gasoline and how these determinants can be simulated to allow an plausible estimation of gasoline demand reduction, thus oil cost savings.

The Data and Models Used

Historical transport and economic time series data were used in the empirical analysis of the demand determinants of gasoline and vehicles. PHEV data was derived from simulated models estimated in reviewed research as well as surveys undertaken by relevant government and NGO entities. Historical time series data for energy (oil and petroleum) was accumulated from the U.S. Department of Energy, Energy Information Administration and U.S. Environmental Protection Agency. Driving and vehicle characteristics data was accessed from reports and archives by US Transportation Department, American Public Transportation Association and American Automobile Manufacturers Association. Data on PHEV simulations and testing was obtained from Argonne National Laboratory, Alternative Fuels Data Center, as well as the papers reviewed. All household characteristics data and macroeconomic data were acquired from the U.S. Census Bureau, U.S. General Services Administrations, U.S. Department of Labor and St Louis Federal Reserve.

A number of surveys were consulted to gain further insight into the purchasing behavior of households and their travel routines; these were obtained from the U.S. Department of Commerce, National Household Travel Survey and an independent market research firm known as Harris Interactive. From these reports, datasets and surveys, a total of 104 different variables were acquired over the time period from 1960 to 2008. (Note: Not all variables had data for this entire period, regression models were adjusted accordingly). Given the complexity involved in attempting to estimate the demand determinants of gasoline and the propensity to drive an additional mile, an **uncompensated demand function** was stipulated for households in the following form:

$$\textbf{Gas Demand} = GD(V_t, O_t, VMT_t, MPG_t, E_t, PCE_t, DI_t)$$

Where **GD** was Gas demand, **V** the number of vehicles in use, **O** is the operating cost per mile, **VMT** is Vehicle Miles Traveled, **MPG** is the miles per gallon, **E** is the number of households employed, **PCE** stands for the Personal Consumption Expenditure of Households and **DI** is the Disposable Income and **t** indicates values at time t. Substitute prices were not included as there currently is no alternative/substitute for gasoline!.

As illustrated above, the household is the most persuasive game changing player in the current US economy, where consumption accounts for around 67% of GDP. Policies and government regulation and action can only take an idea, energy source or technology so far. It is up to the consumer to dissect all information presented and use it to make a rational decision based on the best interests of themselves, their families, their neighboring communities and their country. The prevailing problem seems to be the misinformation presented to the consumer creating a smoke screen which blinds the consumer from making a case for any alternative in transportation (for example Hydrogen power & corn ethanol). A recent survey study conducted by Harris International into the awareness of a U.S. adult of PHEV technology showed the following:

Table 2: Harris International Survey - *"How familiar are you with plug-in hybrid electric engine technology?"*

	Total	Male	Female
Base	965	534	431
	%	%	%
TOP 3 BOX (NET)	**23**	**30**	**16**
Extremely familiar	3	5	1
Very familiar	6	10	2
Familiar	14	15	13
BOTTOM 2 BOX (NET)	**76**	**70**	**84**
Somewhat familiar	29	30	28
Not at all familiar	47	40	56

Source: ***Harris Interactive AutoTECHCAST online survey, 2007***

From this survey it is clear to see that of the 965 households questioned, 76% did not really have an idea of what a PHEV was, where almost half the surveyed individuals had not heard of this form of technology, ever. There is no public information on a revolutionary technology that could literally save households around $3,000 per year (Vyas, A. *et al*, 2001) while at the same time reducing 40% of greenhouse gas emissions (Greene *et al, 1998),* and significantly, if not entirely, reducing the price and scarcity premium encompassed in gasoline prices.

Furthermore, surveys conducted by Department of Energy in 2007 asked a group of U.S. adults specific questions pertaining to PHEV as well as specific choice variables considered before purchasing a new car. The results, (see appendix tables 4A & 5A), proved very interesting. The first showed that, on average, both educated, those whom attended college, and non college graduates would tend to choose a PHEV 25% of the time. The same result persisted for the two different income levels. Given that there has never been a PHEV commercially produced to date, coupled with limited information about the technology, the fact that in each case around 25% of the people choose this new, relatively unknown technology was a great achievement. One can only speculate how the consumer would react once positive press and eye catching advertising come into play enhancing the desirability and 'must have' appeal of the vehicle. A positive first step!

The scenario depicted above is in essence the problem at hand, uninformed and unaware consumers. The only way PHEV could make it to market, is if consumers ask for it. However, one cannot demand something they don't know exists! Marketability of these vehicles should be relatively simple when one thinks about the savings and benefits to both the household, national security and the environment. However, for some reason, demand is constrained by the lack and/or misinformation core to the fundamental ideals of a household, in essence the Explanatory Variables to be assessed:

- **Cost Component** (Energy Prices & Operating Cost/mile),
- **Expenditure (Income) Effect** (Disposable Income & PCE),
- **Usage** (miles driven, age of vehicles, Number of Vehicles in use & Number of drivers)
- **Efficiency** (MPG).

To estimate the change in gasoline demand and its prevalence in our daily lives, Ordinary Least Square (OLS) Linear Regression Models with Robust Standard Errors were used with the following linear regression specification:

$$\boldsymbol{Gas\ Demand = \alpha + \beta_1 Opt.Cost + \beta_2 Efficiency + \beta_3 Usage + \beta_4 Income + \varepsilon}$$

Safety is also paramount, but given that these cars will vary very little to the ICV counterparts in terms of external structural make-up, this was not included in the model.

Empirical Results

As stated above, change in gasoline demand was the explanatory variable of interest. Four OLS linear regression models, with robust standard errors were estimated below:

Table 3: Ordinary Least Squares Regression model - Effective Change in Gasoline Consumed in US given changes in Household Characteristics and Market Factors

Dependant Variable:	**Change in Gasoline Consumed**			
Regression Model Number	**1**	**2**	**3**	**4**
Constant	0.1301743***	0.0811825*	0.0177**	-0.1866*
	(0.0511008)	(0.0437406)	(0.0038)	0.1060
Gasoline Price	-0.0005313***	-0.0005378***		-0.0003607***
	(0.0000941)	(0.0000859)		(0.0000644)
U.S. Cars and Trucks in Use	0. 00000105			
	(0.000000825)			
Vehicle Miles Traveled (VMT)	-0.000000017	-0.000000136***		
	(0.0000000502)	(0.0000000493)		
Vehicle Miles Traveled (VMT), Lagged Variable				-0.000000103***
				(0.0000000419)
Miles Per Gallon (MPG)	-0.0091925***			
	(0.0035766)			
Miles Per Gallon (MPG) % Change		-0.2746601**		-0.2858697***
		(0.1352052)		(0.113937)
Personal Consumption Expenditure		0.0000258*		
		(0.0000145)		
Median Age of Vehicle		0.0231333**		
		(0.011231)		
Alternative Fueled Vehicles Used % Change			-0.0434***	
			(0.0207)	
Operating Cost per Mile % Change			0.2300***	
			(0.0297)	
Number of Licensed Drivers in US				0.00000279***
				(0.00000114)
% Change in Disposable Income				0.5300**
				(0.1907734)
Summary statistics				
R-squared	0.6334	0.7595	0.6757	0.7810
F-statistic	9.6100	22.5200	0.0001	60.6300
Durbin-Watson D-Statistic	1.5431	2.2301	1.5911	1.9595
Number of Observations (n)	30	30	12	30

, **, * indicates significance at the 90%,95%, and 99% level, respectively. Standard errors are in parenthesis*

In regression model 1, *a prior* signs on the coefficients for gasoline prices and MPG were in line with the models results and were found to be statistically significant at the 1% level. The R-squared was measured at 0.6334 which implies the model was a good fit and the D-stat measured at 1.54 implies a relatively low presence of autocorrelation between the variables. The variables VMT and Vehicles in use were found to be insignificant while their coefficient signs were also misleading, against *a prior* expectorations. The two coefficients of interest were that of Gas Price and MPG where it was shown that a $1.00 increase in the price of a gallon of gasoline would yield a 0.05% decrease in the demand and consumption of gasoline. This validates the high price inelasticity of demand calculated by Huntington (2009). MPG showed that a 1 MPG increase in the efficiency of a vehicle would result in a decrease in gasoline consumed of 0.9%! This clearly indicates how significant the role of vehicle efficiency is in regard to the consumption of gasoline.

Regression model 2 regressed the variables of Gasoline Price, VMT, MPG % Change, Personal Consumption Expenditure (PCE) and Median Age of Vehicle on the change in gasoline demand. Gas prices and VMT where significant at the 1% level, MPG and median age of vehicles were significant at the 5% level. PCE was significant at the 10% significance level, the model was measured to have a R-squared of 0.76 which illustrated the model was a good fit, the D-stat was measured at 2.20 which implies no presence of autocorrelation among the variables. Gasoline price inelasticity is again expressed in this model where a $1 increase in gas prices would result in a 0.05% decrease in gasoline consumed; the coefficient's sign was also in line with *a priori* expectations. VMT's coefficient was surprising as was negative when *a priori* expectation was for a positive relationship to exist. According to the model an increase of 1 million MT would result in 0.013% decrease in gasoline consumption, reasoning for this could be that the majority of additional miles driven were free-way miles. This would imply that, on average, a vehicle's speed would reach higher efficiency (MPG) levels with less frequent stops (see table 4A in appendix). The result would be an overall decrease in gasoline consumed, although the overall result does not follow economic theory of demand and supply. There could be a problem with endogeneity or multi-colinearity between this variable and others in the model. A 1% increase in MPG would result in a 0.27% decline in gasoline consumed, again a rather significant decrease in consumption for a modest increase in vehicle efficiency. PCE along with the median age of a vehicle showed to positively affect the consumption of gasoline. A $1,000 (per household) increase in PCE would result in 0.00258% increase in gasoline consumption. This validates the high income inelasticity of demand for gasoline. A 1 year increase in the age of a car resulted in a 2.3% increase in gasoline consumption. The last variable, age of vehicle, further expressed how efficiency plays a pivotal role in gasoline demand, above income and price (due largely to their high relative inelasticity) as it is assumed the older a car is the more inefficient it would tend to be. It is illustrated by the graph below (see graph 1A in appendix) that over the 36 year period in question, MPG increased over time however, the median age of a vehicle has also continually increased. This implies that more than ever, old inefficient vehicles remain in the fleet further enhancing the demand for gasoline.

Regression model 3 estimated the effect of the % change in AFVs in market right now and their impact on gasoline demand. The % change in Operating cost per mile was also included to assess its impact on demand. Due to limited data being available, as only 695,000 AFVs were on the road, only 12 years of observations were utilized. Both signs of the coefficients in question were in line with *a priori* expectations and both were statistically significant at the 1% level. The R-squared was measured at 0.65 which again implies the model was a good fit and the D-stat was calculated at 1.59 which implies a relatively low possibility of autocorrelation. It was shown that as AFVs penetrating the fleet increase by 1%, gasoline consumption would decrease by 0.043%, further bolstering the case for the electrification of transportation. Even though this statistic is relatively small, mass adoption of these vehicles could drastically change the impact. Operating cost per mile was assumed to possibly suffer from endogeneity due to gasoline costs being incorporated in the variable. It was shown however, that a 1% increase in operating costs would result in an increase in gasoline consumed of 0.23%. This result further validates the significant role gasoline plays in the operating cost of an ICV.

The fourth regression was a modification of regression model 1 however, now incorporating the number licensed drivers in the US and the change in disposable income of adults in the US. VMT was now used adjusted for a 1 period lag on the data set. This was to inspect whether there was a delay to change in gasoline demand as the number of miles driven changed. A change in MPG and gasoline prices were again used to determine the effectiveness of the other variables in explaining gasoline demand and whether or not these variables altered significantly from previous regressions. All variables were statistically significant at the 1% level except for the change in disposable income which was significant at the 5% level. The data and model were deemed to be a good fit with an R-squared of 0.78 and a D-stat calculated at 1.95, indicating no presence of autocorrelation. The gasoline price coefficient was relatively unchanged from the first and third models estimations. Here a $1 increase led to a 0.04% decline in gasoline consumed. A 1% increase in MPG was estimated to result in a 0.29% decrease in gasoline demand, very similar to the estimated result in model 2. Here even with the lagged effect on VMT, the result was perplexing as again it showed a decrease in gasoline consumed as VMT increased. This result, even though significant, needs further attention as it could possibly suffer from multicollinearity or a severe case of endogeneity with the dependant variable. An increase of 1,000,000 drivers would increase demand for gasoline by 0.0279%. It was also estimated that a 1% increase in disposable income would lead to a 0.53% increase in gasoline demand, which makes perfect economic sense as incomes rise so will the propensity to drive, positively affecting the demand for gasoline as shown in the model.

I feel that both the OLS regression models and the static-fixed simulation model are externally valid across all AFV technologies. On another note, each of these models could suffer from what is known omitted variable bias. However, in each case the model was constructed using sound economic judgment and theory. It would be impractical to include each and every variable as this would essentially lead to biased estimators. The best possible models and variables were specified and estimated to give the results above. With more time, these models can be further perfected and additional years of data could be assimilated into the regressions.

Conclusion

This paper showed that the average household consumer in the US is still relatively oblivious to the fact that they are almost 100% dependent on gasoline as a means of mobility. Without gasoline (oil), they and the rest of the economy could literally be made immobile with dire socio-economic ramifications. What was briefly experienced in October of 1973-74, an entire economic collapse resulting primarily from a reduction in the supply of oil, would very easily recur. The first, second and fourth regression models reiterated the presence of severely high price and income inelasticity of demand for gasoline. This is portrayed by many other research papers reviewed. The third regression showed that, if given options (AFVs), consumers that are willing to make the switch, could substantially reduce their gasoline consumption. This was also expressed in models 1, 2 and 4 where the coefficient of MPG was used to estimate the efficiency effect on gasoline demand. The static simulation model estimated that a household could experience substantial annual savings resulting from the switch in both gallons of gasoline and cost savings from reduced fuel expense. The conversion of the fleet from ICVs to PHEVs over the 15 year period could allow the US to become oil independent from foreign unfriendly suppliers, significantly bolstering the domestic economy, national accounts and national security, *cetris paribus.* It was measured that the cost of $250 billion per year is what was required by government to ascertain this result. This cost (investment) could be shared by government, car producers and consumers in the form of tax rebates and write-offs and subsidies. Hold in mind as mass production of these vehicles takes place we expect economies of scale and learning by doing to facilitate a reduction in the costs overtime.

Lest we not forget the most important benefits derived from this undertaking, that of the sustainability of humanity. Through the modification of the light vehicle fleet, from ICVs to PHEVs, independence from oil could be realized which would lead to significant reductions in greenhouse gas emissions, enhancing the standard of living for all households through fuel savings and the reducing the volatility and scarcity in energy supplies. Waging unnecessary resource wars over non-renewable greenhouse gas emitting fuels would become nothing more than a piece of history. This evolution in transportation would essentially allow for the preservation of both our economy and planet for future generations to come.

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Appendix

Table 1A: Daily Driving Distance of US Household, 2007

Average annual vehicle trips per household	459
VMT/yr Total (2007)	3,023,761
Driving Days per Year	365
Average Daily MT	**18.1**

Table 2A: Trip Statistics by Trip Purpose, 2001 NHTS

	Share of trips	vehicle-miles traveled	Trip length (miles)	Trip duration (minutes)
Trip purpose				
To/from work	22.1%	27.0%	12.1	22.3
Work-related business	4.1%	8.4%	20.3	30.9
Shopping	21.1%	14.5%	6.7	14.4
Other family/personal business	24.7%	18.7%	7.5	15.2
School/church	4.9%	3.7%	7.5	15.8
Medical/dental	2.2%	2.2%	9.9	20.7
Vacation	0.4%	1.8%	47.4	59.6
Visit friends/relatives	6.3%	9.4%	14.9	24.4
Other social/recreational	13.7%	13.2%	9.6	18.2
Other	0.5%	1.0%	18.1	31.4
All	99.9%	100.0%	9.9	18.7
Source:				
Generated from the National Household Travel Survey Internet site: nhts.ornl.gov.				

Table 3A: Driving Cycle Attributes

	Test Schedule				
	City	Highway	High Speed	AC	Cold Temp
Trip type	Low speeds in stop-and-go urban traffic	Free-flow traffic at highway speeds	Higher speeds; harder acceleration & braking	AC use under hot ambient conditions	City test w/colder outside temperature
Top speed	56 mph	60 mph	**80 mph**	54.8 mph	56 mph
Average speed	20 mph	48 mph	48 mph	22 mph	20 mph
Max. acceleration	3.3 mph/sec	3.2 mph/sec	**8.46 mph/sec**	5.1 mph/sec	3.3 mph/sec
Simulated distance	11 mi.	10 mi.	8 mi.	3.6 mi.	11 mi.
Time	31 min.	12.5 min.	10 min.	9.9 min.	31 min.
Stops	23	None	4	5	23
Idling time	18% of time	None	7% of time	19% of time	18% of time
Engine startup[a]	Cold	Warm	Warm	Warm	**Cold**
Lab temperature	68-86° F	68-86° F	68-86° F	**95° F**	**20° F**
Vehicle air conditioning	Off	Off	Off	**On**	Off
Source:					
U.S. Department of Energy and U.S. Environmental Protection Agency, Fuel Economy Website, www.fueleconomy.gov.					
[a] A vehicle's engine doesn't reach maximum fuel efficiency until it is warm.					

Table 4A: U.S Department of Energy, Survey - "If Gas Prices stayed between $2.50 and $3.00 would you...?"

		Income		Education	
	Total	**> $50k**	**< $50k**	**No College**	**College**
Observations	963	210	336	336	601
Spend $2000 to get a HEV, increase MPG by 40%	409	103	148	227	262
Spend $4000 on a PHEV20, $0.75 equivalent gas price	249	54	85	89	153
No buy a ICV	258	43	94	91	162
Don't know	46	10	6	20	25

" Table 5A: U.S Department of Energy, Survey - Did you consider Fuel economy when comparing Vehicles"

		Income		Education	
	Total	**> $50k**	**< $50k**	**No College**	**College**
	1000	250	401	403	588
Yes	561	139	250	216	340
No	365	93	143	134	229
Never purchased a Car	57	16	7	43	12
Don't know	17	2	2	10	8

Graph 1A: MPG and Median Age of Vehicles