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DISSERTATION

Three Essays in Transportation Energy and Environmental Policy

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This document was submitted as a dissertation in March 2010 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Martin Wachs (Chair), Thomas Light, and John Graham.

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ABSTRACT

Concerns about climate change, dependence on oil, and unstable gasoline prices have led to significant efforts by policymakers to cut greenhouse gas (GHG) emissions and oil consumption. The transportation sector is one of the principle emitters of CO2 in the US. It accounts for two-thirds of total U.S. oil consumption and is almost entirely dependent on oil. Within the transportation sector, the light-duty vehicle (LDV) fleet is the main culprit. It is responsible for more than 65 percent of the oil used and for more than 60 percent of total GHG emissions. If a significant fraction of the LDV fleet is gradually replaced by more fuel-efficient technologies, meaningful reductions in GHG emissions and oil consumption will be achieved.

This dissertation investigates the potential benefits and impacts of deploying more fuel-efficient vehicles in the LDV fleet. Findings can inform decisions surrounding the development and deployment of the next generation of LDVs. The first essay uses data on 2003 and 2006 model gasoline-powered passenger cars, light trucks and sport utility vehicles to investigate the implicit private cost of improving vehicle fuel efficiencies through reducing other desired attributes such as weight (that is valued for its perceived effect on personal safety) and horsepower. Breakeven gasoline prices that would justify the estimated implicit costs were also calculated. It is found that to justify higher fuel efficiency standards from a consumer perspective, either the external benefits need to be very large or technological advances will need to greatly reduce fuel efficiency costs.

The second essay estimates the private benefits and societal impacts of electric vehicles. The findings from the analysis contribute to policy deliberations on how to incentivize the purchase and production of these vehicles. A spreadsheet model was developed to estimate the private benefits and societal impacts of purchasing and utilizing three electric vehicle technologies instead of a similar-sized conventional gasoline-powered vehicle (CV). The electric vehicle technologies considered are gasoline-powered hybrid and plug-in hybrid

electric vehicles and battery electric vehicles. It is found that the private benefits are positive, but smaller than the expected short-term cost premiums on these technologies, which suggest the need for government support if a large-scale adoption of electric vehicles is desired. Also, it is found that the net present values of the societal benefits that are not internalized by the vehicle purchaser are not likely to exceed $1,700. This estimate accounts for changes in GHG emissions, criteria air pollutants, gasoline consumption and the driver's contribution to congestion.

The third essay explores the implications of a large-scale adoption of electric vehicles on transportation finance. While fuel efficiency improvements are desirable with respect to goals for achieving energy security and environmental improvement, it has adverse implications for the current system of transportation finance. Reductions in gasoline consumption relative to the amount of driving that takes place would result in a decline in fuel tax revenues that are needed to fund planning, construction, maintenance, and operation of highways and public transit systems. In this paper the forgone fuel tax revenue that results when an electric vehicle replaces a similar-sized CV is estimated. It is found that under several vehicle electrification scenarios, the combined federal and state trust funds could decline by as much as 5 percent by 2020 and as much as 12.5 percent by 2030. Alternative fee systems that tie more directly to transportation system use rather then to fuel consumption could reconcile energy security, environmental, and transportation finance goals.

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ABBREVIATIONS

ARRA	American Recovery and Reinvestment Act
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CH4	Methane
CPI	Consumer Price Index
CV	Conventional Vehicle (in this paper, gasoline-powered with internal combustion engine)
CO	Carbon monoxide
CO2	Carbon dioxide
CO2-equivalent	Carbon dioxide equivalent; the amount of carbon dioxide (in grams) emitted into the atmosphere that would result in equivalent global warming potential as a given weight of another greenhouse gas
DOE	US Department of Energy
DOT	US Department of Transportation
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EPA	US Environmental Protection Agency
EPRI	Electricity Power Research Institute
Fuel Cycle	Also called well-to-tank; activities linked with fuel including raw material extraction, production, and distribution
GHG	Greenhouse gas
GM	General Motors
GREET	Greenhouse gas, Regulated Emissions, and Energy use in Transportation model developed by Argonne National Laboratory
HEV	Hybrid electric vehicle (in this paper , hybrid gasoline-electric vehicle)
ICE	Internal Combustion Engine
IRS	Internal Revenue Services

kWh	Kilo Watt hour
LDV	Light Duty Vehicles
Mpg	Miles per gallon
MSRP	Manufacturer Suggested Retail Price
NGCC	Natural Gas Combined Cycle
NHTSA	US National Highway Transportation Safety Administration
NOx	Oxides of Nitrogen
NPV	Net Present Value
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
PHEV-X	Plug-in Hybrid Electric Vehicle (in this paper, plug-in hybrid gasoline electric vehicle) with an all-electric driving range of X miles
PM	Suspended particulate matter in the air
PM2.5	Particulate matter less than 2.5 μm in diameter
PM10	Particulate matter less than 10 μm in diameter
PV	Present Value
SOx	Sulfur oxides
SOC	State-of-Charge of the battery
SUV	Sport Utility Vehicle
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compounds
WTW	Well-to-wheel; raw material extraction, fuel production and distribution, and the use of a fuel in the vehicle
ZEV	Zero Emission Vehicle
ZEV AT	Advanced Technology Zero Emission Vehicle
PZEV	Partial Zero Emission Vehicle

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FIRST ESSAY: THE IMPLICIT PRIVATE COST OF FUEL EFFICIENCY: HOW EXPENSIVE WOULD GASOLINE NEED TO BE TO INDUCE CONSUMERS TO DRIVE MORE FUEL-EFFICIENT CARS?

INTRODUCTION

High demand for gasoline in the US transportation sector is leading to negative consequences for the environment and increasing dependency on oil. Due to these concerns, the US Energy Independence and Security Act of 2007 ((EISA 2007); P.L.110-140) requires more stringent corporate average fuel economy (CAFE) standards be set for light-duty vehicles (LDVs) for model years 2011 through 2020. In May 2009, President Obama proposed that these requirements, specified by Sub-title A of EISA 2007 (P.L.110-140), be accelerated (The White House 2009). The new provision aims to ensure that, by 2016, the industry-wide CAFE for all new passenger cars and light trucks combined will be at least 35.5 miles per gallon (mpg).

Even though the government is concerned and is taking actions, the consumers and manufacturers are not necessarily acting in the same way. Actually, data shows that recent gains in the vehicle fuel efficiency have been offset by increases in vehicle size and performance (Lutsey and Sperling 2005; An and DeCicco 2007). Of course, higher fuel efficiency is valued by consumers, but it comes at a cost. In the short run, other valued car attributes such as weight (that is desired for its perceived effect on personal safety) and horsepower can be traded to achieve improved fuel efficiency. In the long run, technological innovations may allow greater fuel efficiency for a given level of weight and power. In both cases, consumers eventually need to pay. However, there must be some scenarios under which payment is seen as justified by consumers because their private interests intersect with the interests of society. Consumer valuation of vehicle attributes is a vital piece of information to help indentify such scenarios.

Consumer valuation of vehicle attributes is an important part of a cost-benefit analysis of fuel-economy regulations and carbon-control policies in the transportation sector. There is an extensive econometric literature on consumers’ valuation of vehicle attributes. However, the literature is based on old data and provides inconsistent estimates for the values consumers ascribe to different vehicle attributes (for examples see Waugh 1928; Court 1939; Griliches 1961; Triplett 1969; Goodman 1983; Ohta and Griliches 1986; Espey and Nair 2005). This paper differs from previous studies in that it uses primary data on 2003 and 2006 model gasoline-powered passenger cars, light trucks and SUVs (as opposed to passenger cars only) and looks at breakeven gasoline prices that induce consumers to drive more fuel-efficient vehicles. More specifically, this study answered the following research questions:

- With the current internal combustion engine technology, what are the premiums consumers are willing to pay for valued attributes of passenger cars, light trucks and sport utility vehicles (SUVs) that run on gasoline?
- With the current internal combustion engine technology, what is the implicit consumer cost of each unit increase in fuel economy?
- How expensive would gasoline need to be in order for consumers to be willing to trade personal safety and power for more fuel economy?

The empirical models estimated in this paper indicate that US consumers value fuel efficiency for its effect on operating costs and that they place a high value on weight and horsepower. It appears that fuel prices would need to be much higher to induce consumers to choose more fuel-efficient vehicles and that to justify higher fuel efficiency standards from a consumer perspective at 2006 gasoline prices, either the external benefits need to be very large or technological advances will need to greatly reduce fuel efficiency costs.

The layout of the paper is as follows. The next section describes the approach. This is followed by a section on data and one on the empirical results. Conclusions and discussions are in the final section.

APPROACH

In this paper, hedonic modeling is used to estimate the marginal values people assign to different vehicle attributes. Next, a technological model that links the fuel efficiency of a vehicle to its different attributes is estimated. Using the results of these models, the minimum gasoline price that equates fuel cost savings from better fuel efficiency to the additional vehicle cost to acquire the improved fuel efficiency is calculated. The breakeven gasoline price is calculated under three scenarios that are characterized by expectations about future fuel prices relative to the price of other goods and services and by different discount rates.

The Hedonic Model Estimation

Estimating consumers' valuation of vehicle attributes is useful in performing cost-benefit analysis of fuel-economy regulations and carbon-control policies in the transportation sector. Here, a hedonic modeling approach is used to estimate the values consumers attach to different attributes of LDVs (cars, light trucks and SUVs). This approach has been widely used in the econometric literature to estimate consumers' valuation of attributes of a variety of goods (for examples see Waugh 1928; Court 1939; Griliches 1961; Ohta and Griliches 1986; Feitelson, Hurd et al. 1996; Baranzini, Ramirez et al. 2008).

The hedonic approach assumes that the relationship between prices and vehicle attributes provides an estimate of the value of those attributes. In a competitive equilibrium, the price of a vehicle is a function of the implicit prices of the bundle of its attributes. For theoretical foundations of the hedonic approach see (Muellbauer 1974; Rosen 1974; Ohta and Griliches 1976). While multiple functional forms were explored, the data suggest that a linear model is appropriate. Thus, as shown in Equation 1.1, it is assumed that the hedonic model takes a linear form:

$$P_i = \beta_0 + \sum \beta X_i + \alpha G_i + e \qquad (1.1)$$

where P_i represents the price of vehicle i and G_i represents the fuel efficiency of vehicle i in mpg. Earlier studies exploring hedonic price estimation in the context of vehicle attributes argue that consumers do not value fuel efficiency per se, and that the amount of gasoline consumed enters the customers' utility maximization only through the budget constraint (Ohta and Griliches 1986). However, given the recent public outcry against global warming and energy insecurity, this may not necessarily be true anymore. Thus, I consider fuel efficiency to be an attribute with both intrinsic and instrumental values. α indicates the marginal price paid for an additional unit of miles per gallon. X represents a matrix of vehicle attributes such as weight, horsepower, and length. Physical characteristics such as weight act as surrogates for valued attributes such as personal safety. Table 1.1 presents desired vehicle characteristics considered in this study and their corresponding metrics. The $\beta's$ are the implicit marginal prices paid for units of each attribute, all else being equal, and e is assumed to be independent and identically distributed error terms. In total, four linear models are estimated using observations for 2003 passenger cars, 2006 passenger cars, 2003 light trucks and SUVs, and 2006 light trucks and SUVs.

Table 1.1: Desired Attributes of Cars, Light Trucks and SUVs

Valued Attribute	Metrics	
	Passenger Cars	Light Trucks and SUVs
Power	Horsepower (hp)*	Horsepower (hp)
Personal Safety	Weight (lbs)	Weight (lbs)
Ease of driving/handling	Automatic Transmission (yes, no)	Automatic Transmission (yes, no) All-wheel-drive (yes, no)
Styling	Length (in) Convertible (yes, no) Categorized as Luxury (yes, no)	Categorized as Luxury (yes, no)
Type/Size	Coupe (yes, no) Sedan (yes, no) Hatchback (yes, no) Wagon (yes, no)	Minivan (yes, no) Van (yes, no) SUV (yes, no) Pickup (yes, no) Average Playload (lbs)
New or Used	New (yes, no)	New (yes, no)
Fuel Economy**	Mileage per gallon (mpg)	Mileage per gallon (mpg)

Note: * maximum power output of internal combustion engines of vehicles; ** a weighted average based on an EPA assumption of 55% city driving and 45% highway driving.

The Technological Model Estimation

The fuel efficiency of a vehicle is a function of its weight, horsepower and other attributes. Several studies have attempted to predict fuel efficiency from other vehicle attributes using regression models. They suggest weight and power are important explanatory factors (Henderson and Velleman 1981; DeCicco and Ross 1996; An and DeCicco 2007). Here, using regression analysis, the effect of weight and horsepower on fuel efficiency (measured in miles per gallon) for 2006 models are estimated. This is presented in Equation 1.2:

$$G_i = \lambda_0 + \lambda_W W_i + \lambda_H H_i + e \tag{1.2}$$

where G_i represents the fuel economy of vehicle i. W represents the weight of the vehicle, H represents its horsepower, and $\lambda's$ are the regression coefficients. e is assumed to be independent and identically distributed error terms.

The Implicit Cost Estimation and Breakeven Gasoline Prices

Looking at the short run, over which the gasoline engine technology is fixed, manufacturers would likely need to reduce weight and/or horsepower to increase fuel efficiency. Note that weight reduction can be accomplished by a variety of techniques ranging from using lower density materials (e.g. aluminum or plastic instead of steel) or lighter but stronger ones (e.g. high-strength alloy steel instead of cold-rolled steel), to redesign components of vehicles (DOT 2006). The question is what would be the implicit cost of each unit increase in miles per gallon to consumers if this increase were to be achieved via either weight or horsepower reduction. I use the 2006 hedonic and technological models to estimate this implicit cost as follows:

$$ICW = \frac{-\beta_W}{\lambda_W} + \alpha \tag{1.3}$$

$$ICH = \frac{-\beta_H}{\lambda_H} + \alpha \tag{1.4}$$

where Equation 1.3 and Equation 1.4 represent the implicit cost to consumers of a unit increase in fuel efficiency via weight and horsepower reduction, respectively. Note that β_W, β_H and α are estimates of the prices that consumer is willing to pay for an additional unit of weight, horsepower, and fuel economy, respectively (Equation 1.1); λ_W and λ_H are estimates of the effects of weight and horsepower on the fuel economy (Equation 1.2).

While there is an implicit cost for improved fuel efficiency as a result of reduction in horsepower or weight, fuel cost savings have the potential to recoup some or all of that cost. The question is how expensive would gasoline need to be to make fuel cost savings large enough to offset the full cost of fuel economy improvements?

To answer this question, results of the hedonic and technological models are employed. The expected fuel cost saving from each additional mile per gallon over the lifetime of an average 2006 model vehicle is estimated from a vehicle owner's perspective, using data on survival rates and average annual miles driven per vehicle type. These data were taken from the Transportation Energy Data Book 2009 (Davis, Diegel et al. 2009) and are presented in details in Appendix A.

In estimating the expected fuel cost savings, three scenarios were considered: HighPriceLowDiscountRate, MediumPriceMediumDiscountRate, and LowPriceHighDiscountRate. Under the HighPriceLowDiscountRate scenario it is assumed that, at the time of purchase, consumers have a high discount rate (10%) and believe that gasoline is going to be cheaper relative to the price of other goods and services over the lifetime of the vehicle. The converse is true for the LowPriceHighDiscountRate scenario, where it is assumed that at the time of purchase consumers have a low discount rate (3%) and believe that gasoline is going to be more expensive relative to the price of other goods and services over time. For the MediumPriceMediumDiscountRate scenario, it is assumed that consumers have a moderate discount rate (7%) and that they believe the price of gasoline does not change relative to the price of other goods and services in the future.

It is further assumed that at the time of the purchase consumers are homogeneous and that they value fuel cost savings over the entire life of a vehicle. It is also assumed that consumers believe that the actual mileage per gallon achieved in-use is the same as the mileage per gallon reported and that this mileage per gallon stays constant over the lifetime of the vehicle.

DATA

Data for 2003 and 2006 new and used gasoline-powered passenger cars, light trucks and SUVs were gathered. Model years 2003 and 2006 were chosen in order to span a period of rapidly escalating fuel prices ($1.14/gallon in 2003 to $2.12/gallon in 2006)(EIA no date).

Data on retail values of cars, light trucks and SUVs were collected from the Kelly Blue Book used car guides (Kelly Blue Book 2004; Kelly Blue Book 2007) and new car price manuals (kelly Blue Book 2003; Kelly Blue Book 2005). The retail values reported are averages of actual prices paid by consumers and not the manufactures' suggested retail prices (MSRPs). The prices were normalized to 2003 values using the Consumer Price Index (CPI) less energy and food, obtained from the Bureau of Labor Statistics (Bureau of Labor Statistics no date) .

Information on vehicle characteristics was collected from Automotive News and Kelly Blue Book websites, and data on fuel efficiency (mpg) were collected from www.FuelEconomy.gov, a website supported by the Environmental Protection Agency (EPA) and the Department of Energy's Fuel Efficiency and Renewable Energy program. Table 1.2 presents the number of observations and Table 1.3 presents the average price, fuel economy, weight and horsepower in the dataset.

Table 1.2: Number of Observations in Dataset

Year	Cars		Trucks	
	New	Used	New	Used
2003	164	173	83	87
2006	137	165	130	143
Sum	301	338	213	230

Table 1.3: Average Fuel Economy, Weight and Horsepower

Model Year/Type	Attribute	
2003 Passenger Cars	Mean Price ($2003)	28,064
	Mean mpg	24.5
	Mean weight (lbs)	3,311
	Hp	199
2006 Passenger Cars	Mean Price ($2003)	33,307
	Mean mpg	24.2
	Mean weight (lbs)	3,473
	Hp	225
2003 Light Trucks and SUVs	Mean Price ($2003)	22,007
	Mean mpg	18.4
	Mean weight (lbs)	5,579
	Hp	204
2006 Light Trucks and SUVs	Mean Price ($2003)	25,325
	Mean mpg	19.4
	Mean weight (lbs)	5,714
	Hp	220

Note: numbers are not weighted by market share.

RESULTS

The Hedonic Model

The hedonic model was used to estimate the values consumers attach to different attributes of light duty vehicles (cars, light trucks and SUVs). The model for passenger cars indicates that buyers value weight (for its perceived effect on personal safety), horsepower, and mileage per gallon. As shown in Table 1.4, in 2003 passenger car buyers paid on average $313.2 for an additional mpg and $12.8 per additional pound, all else being equal. The magnitude of the latter estimate is consistent with that of earlier studies. Earlier studies have reported a range from $0.17 to $13.38 per additional pound, in present value terms at the time of purchase (Greene and Duleep 1992). Moreover, in 2003, consumers paid on average $119.3 for an additional horsepower, all else being equal. In 2006, however, consumers paid on average $483.5 for an additional mpg, $9.9 per additional pound, and $147.2 for each additional horsepower. Even though the price of gasoline nearly doubled from 2003 to 2006, the estimated premiums car buyers paid for mpg, weight and horsepower were not statistically different for these two years, indicating that consumers’ taste for these attributes did not significantly change.

Table 1.4: Estimated Coefficients of Desired Attributes for Passenger Cars

Dependent variable: vehicle price in 2003 dollars		
Sample	2003 model	2006 model
mpg	313.1862*	483.5323*
	(147.217)	(209.4588)
Horsepower	119.3021*	147.2243*
	(7.757958)	(9.174758)
Weight	12.85682*	9.86364*
	(1.391967)	(1.725113)
Number of Observations	337	302
Adjusted R-squared	0.8898	0.8906

* Significance at 5%; (): Standard errors
Regression controls for whether or not the car is a wagon, coupe, sedan, convertible, hatchback, luxury, and new and for the length of the car and the type of transmission. Base category is sedan, used, manual and not luxury.

Note that the magnitude of the estimated passenger car buyer's marginal valuations of each additional mpg in both years is consistent with the expected fuel cost savings under the HighPriceLowDiscountRate scenario. As shown in Table 1.5 below, under a HighPriceLowDiscountRate scenario, the expected fuel cost savings of an additional unit of fuel efficiency (mpg) is estimated to be $370 in 2006 dollars. This number is $690 and $1,160 under the MediumPriceMediumDiscountRate and the LowPriceHighDiscountRate scenarios, respectively. For details on the estimation steps of the fuel cost savings refer to Tables B.1-B.6 in Appendix B.

Table 1.5: Estimated Fuel Cost Savings of an Additional Unit of Fuel Efficiency over the Life of a Vehicle ($2006)

LDV Type	Scenario		
	HighPrice LowDiscountRate	MediumPrice MediumDiscountRate	LowPrice HighDiscountRate
Passenger Cars	370	690	1,160
Trucks and SUVs	680	1,260	2,070

The results of the hedonic model for light trucks and SUVs are presented in Table 1.6. As shown, in 2003, buyers of light trucks and SUVs did not value mpg for its own sake. Note also that the estimated coefficient is statistically insignificant. However, they paid on average $1.9 per pound and $39.3 for horsepower, on the margin. In 2006, consumers paid on average $307.3 for each additional mile per gallon, $3.4 per additional pound, and $39.7 per additional horsepower, all else being equal. The estimated premiums buyers of light trucks and SUVs paid for fuel efficiency and weight were significantly different for 2003 and 2006, indicating a shift in the tastes of the consumers for these two attributes. The estimated premiums for horsepower, however, were not statistically different for these two years.

Table 1.6: Estimated Coefficients of Desired Attributes for Light Trucks and SUVs

Dependent variable: vehicle price in 2003 dollars		
Sample	2003 model	2006 model
mpg	-52.28	307.3132*
	(136.0277)	(117.4517)
Horsepower	39.34*	39.72574*
	(7.038733)	(4.937267)
Weight	1.93*	3.399854*
	(0.4969429)	(0.4250322)
Number of Observations	170	273
Adjusted R-squared	0.8991	0.9260

* Significance at 5%; (): Standard errors
Regression controls for whether or not the vehicle is an SUV, van, pickup, minivan, luxury, all-wheel-drive, and new and for the playload and type of transmission. Base category is pickup, used, manual and not luxury.

The estimated marginal valuations of fuel efficiency for light trucks and SUV buyers indicate that this type of buyer undervalue fuel economy, because the estimated marginal valuations are much smaller than the expected fuel cost savings obtained from the improved fuel efficiency over the life of the vehicle under all three scenarios. The expected fuel cost savings is estimated to be about $670, $1,260 and $2,070 in 2006 dollar values under the HighPriceLowDiscountRate,

HighPriceLowDiscountRate, HighPriceLowDiscountRate, respectively (Table 1.5).

The Technological Model

The effects of different vehicle attributes on fuel efficiency are estimated and the results are presented in Table 1.7. The results suggest that the fuel efficiency of a passenger car decreases by 0.317 mpg for each 100 pound increase in weight and by 0.02 for each unit increase in horsepower. For light trucks and SUVs, the results suggest that the fuel efficiency decreases by 0.2 mpg for each 100 pounds increase in weight and by 0.01 mpg for each unit increase in horsepower.

Table 1.7: Estimated Coefficients in the Fuel Efficiency Function[1]

Dependent variable: Miles per gallon		
Sample	2006 Passenger Cars	2006 Light Trucks and SUVs
Weight	-0.0037004*	-0.0020256*
	(0.0002269)	(0.0001388)
Horsepower	-0.0228605*	-0.0125911*
	(0.0015416)	(0.0022395)
Number of Observations	639	443
Adjusted R-squared	0.7452	0.6493

* Significance at 5%; (): Standard errors

The Implicit Cost of Fuel Efficiency and Breakeven Gasoline Prices

Using the results of the 2006 hedonic and technological models (Tables 1.5, 1.6, and 1.7), the implicit costs of increasing fuel efficiency via weight and horsepower reduction were calculated. These estimates are shown in Table 1.8.

[1] A regression was also run controlling for vehicle size and whether or not it is all-wheel-drive. The results were virtually the same.

Table 1.8: The Implicit Cost of Unit Increase in Fuel Efficiency for 2006 Models

	Passenger car		Light Trucks and SUVs	
	via HP reduction	via Weight Reduction	via HP reduction	via Weight Reduction
A: Reduction in attribute	44 (hp)	270 (lbs)	79 (hp)	494 (lbs)
B: Marginal price paid for attribute ($ 2003)	147.2	9.9	39.7	3.4
C: Cost of reduction in attribute (A*B) ($ 2003)	6,439	2,675	3,153	1,679
D: Marginal price paid for mpg ($ 2003)	483.5	483.5	307.3	307.3
E: Net Implicit Cost (C-D)($ 2003)	5,956	2,192	2,846	1,371
F: Average Price of Cars/Light Trucks & SUVs ($ 2003)	33,307	33,307	25,325	25,325
H: Net Implicit Cost ($ 2006)*	6,347	2,336	3,033	1,461
G: Implicit Cost Relative to Average Price(E/F)	18%	7%	11%	5%

* U.S. Consumer Price Index-all items less food and energy was used to adjust 2003 dollars to 2006 dollars (Bureau of Labor Statistics no date)

The results suggest that, given 2006 prices, the implicit costs of reductions in personal safety and power greatly outweigh fuel cost savings. The question is how expensive 2006 gasoline prices should have been to justify this cost. The answer to this question is presented in Table 1.9 and Figures 1.1-1.4 (see Table B.7-B.15 in Appendix B for details on how these breakeven gasoline prices were calculated). As shown in Figures 1.1-1.4, the implicit cost falls with higher fuel prices and lower discount rates.

Table 1.9: Breakeven Gasoline Prices ($2006)

Scenario	Passenger Cars		Light Trucks and SUVs	
	via Horsepower Reduction	via Weight Reduction	via Horsepower Reduction	via Weight Reduction
HighPriceLowDiscount	36.4	13.4	9.4	4.5
MediumPriceMediumDiscount	31.4	11.6	8.2	4
LowPriceHighDiscount	24.7	9.1	6.6	3.2

Figures 1.1 and 1.2 present the implicit cost of achieving an additional mile per gallon in passenger cars via weight reduction and horsepower reduction, respectively. As shown in these figures, from a vehicle owner's perspective, the implicit cost of achieving an additional mile per gallon in fuel efficiency via weight reduction would have been justified by the resulting fuel cost savings if the price of gasoline had been $13.4, $11.6, and $9.1 per gallon at 3, 7 and 10 percent discount rates, respectively[2]. The cost of such an improvement via horsepower reduction would have been justified if the price of gasoline had been $36.4, $31.4, and $24.7 per gallon at 3, 7 and 10 percent discount rates, respectively.

[2] Note that the average gasoline price in 2006 was $2.12 per gallon.

Figure 1.1: The Implicit Cost of Unit Increase in Fuel Economy for Passenger Cars via Weight Reduction ($2006)

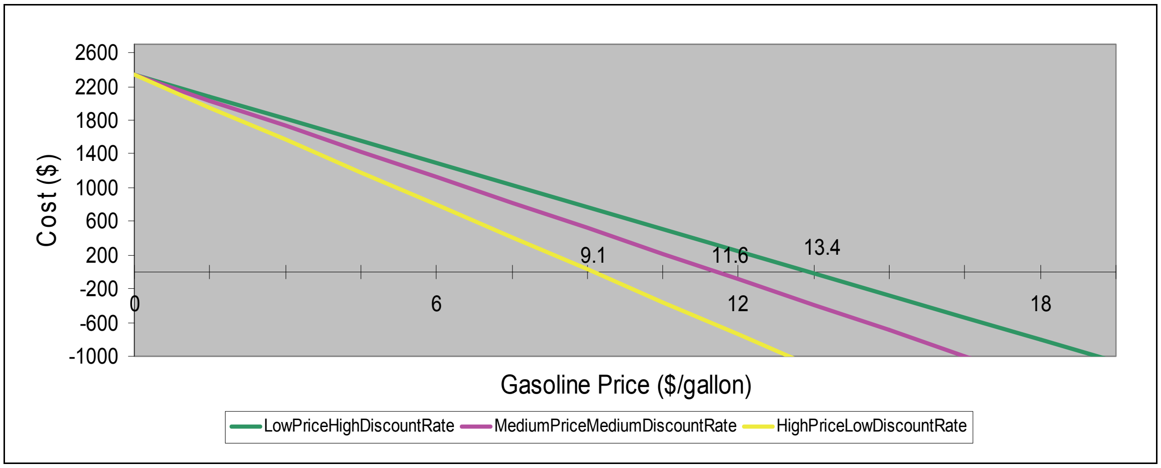
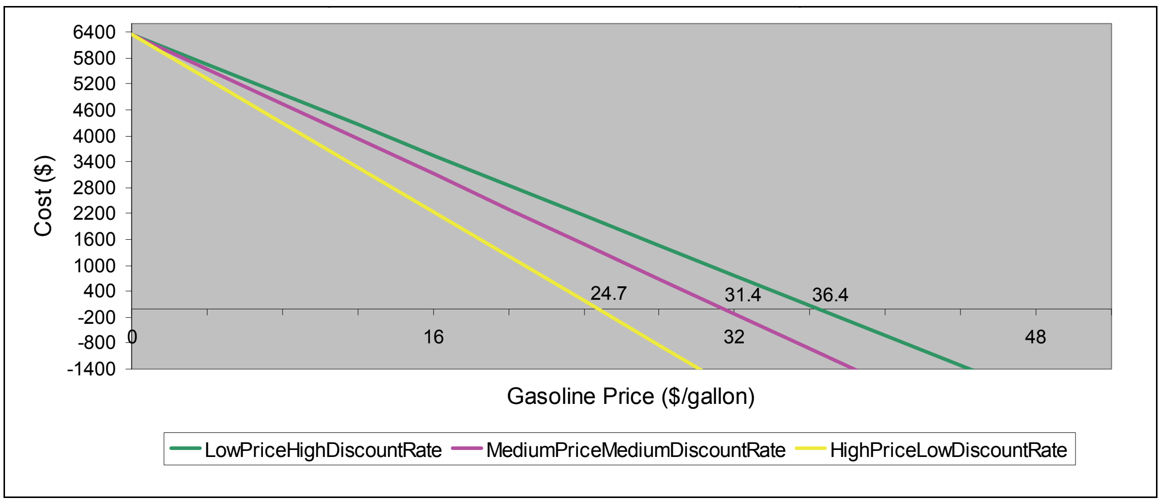


Figure 1.2: The Implicit Cost of Unit Increase in Fuel Economy for Passenger Cars via Horsepower Reduction ($2006)



Figures 1.3 and 1.4 present the gasoline prices that could have justified the implicit cost of achieving an additional mile per gallon in light trucks and SUVs via weight reduction and horsepower reduction. The breakeven gasoline prices are smaller for light trucks and SUVs compared to those estimated for passenger cars. They range from $3.2 to $4.5 per gallon if fuel efficiency improvement is achieved via weight reduction and from $6.6 to $9.4 per gallon if it is achieved via horsepower reduction.

Figure 1.3: The Implicit Cost of Unit Increase in Fuel Economy for Light Trucks and SUVs via Weight Reduction ($2006)

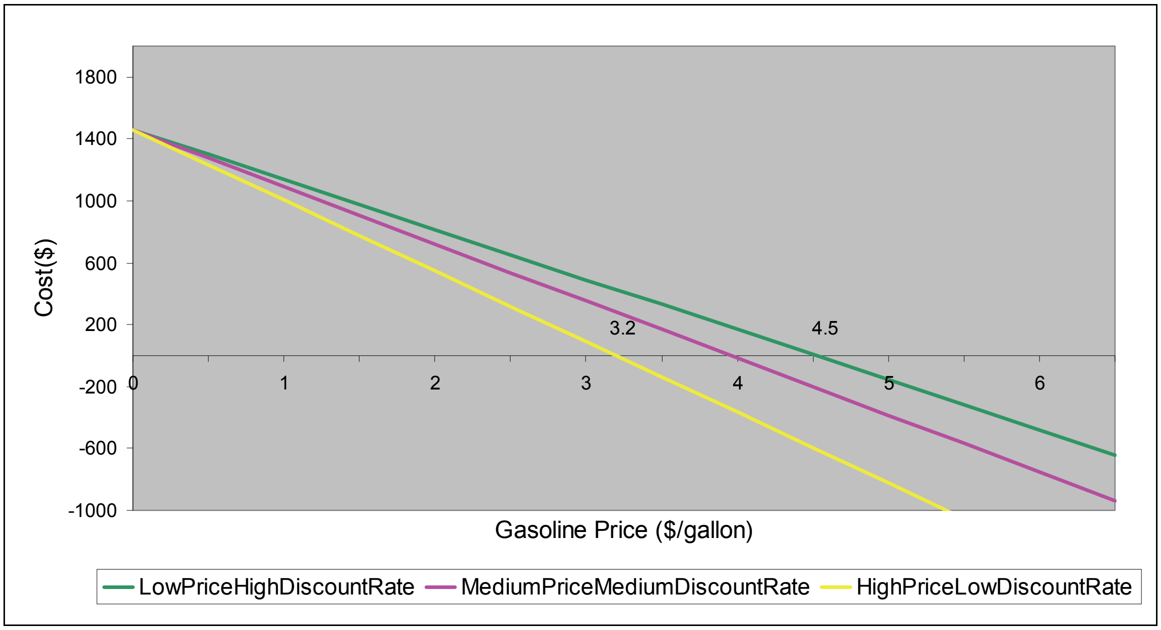
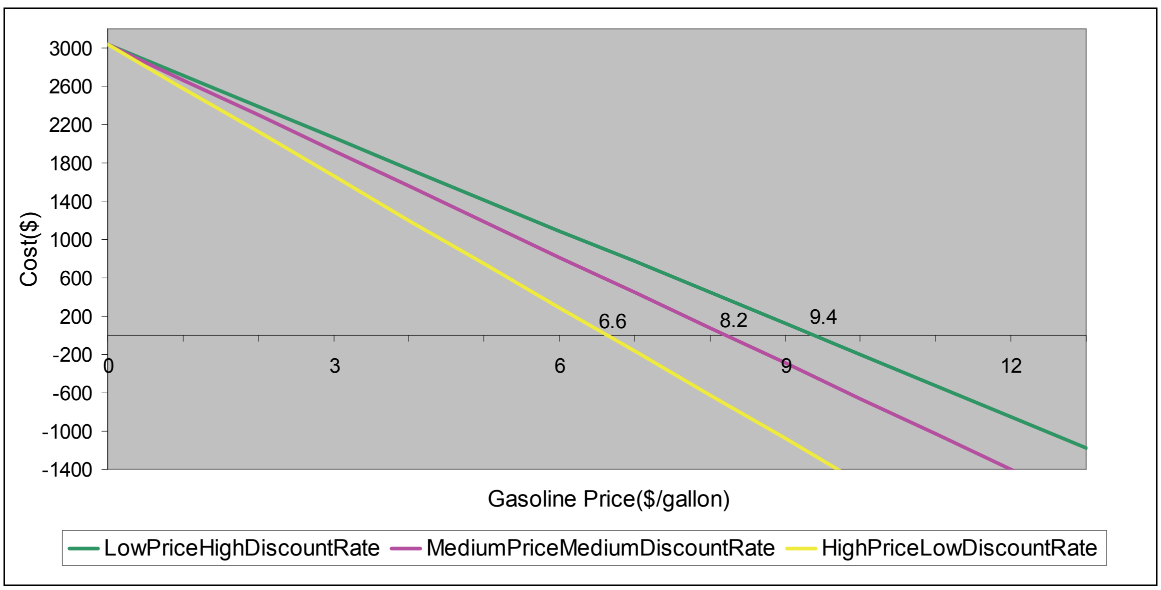


Figure 1.4: The Implicit Cost of Unit Increase in Fuel Economy for Light Trucks and SUVs via Horsepower Reduction ($2006)



DISCUSSION AND CONCLUSIONS

In this paper, the implicit private cost of improving vehicle fuel efficiencies through reducing other desired attributes such as weight and horsepower was estimated. The estimated implicit costs suggest that from a consumer perspective, reaching more fuel efficiency via weight and horsepower reduction is costly, but can be justified at higher gasoline prices. At current prices, consumers choose to drive relatively fuel-inefficient vehicles. They do so because they place a premium on personal safety and power. Given today's internal combustion engine technology, fuel prices would need to be much higher to induce consumers to choose more fuel-efficient vehicles. To justify higher fuel efficiency standards from a consumer perspective at 2006 gasoline prices, either the external benefits need to be very large or technological advances will need to greatly reduce fuel efficiency costs. However, even if in the future new technologies enable consumers to enjoy higher fuel efficiency without compromising weight and horsepower, it is not clear that the tradeoffs would fade away, unless there is significant saturation of demand for this other attributes.

In deriving the implicit cost a number of important assumptions are made. First, it is assumed that all consumers are homogenous and that the hedonic relationship is the same across all consumers. It is obvious that some consumers might value power and/or personal safety less than others. Thus, the aggregate consumer cost of reducing weight could be lessened by reducing weight for classes of cars consumed by individuals who have weaker preferences for weight. I also assume that producers are homogenous and increase fuel efficiency by reducing the weight and/or horsepower of all cars by the same amount. Clearly, the technological relationship between fuel efficiency and power and personal safety varies across manufacturers and car types.

Moreover, the study looks at the short term and assumes that reducing weight and horsepower are the only means of increasing fuel efficiency in gasoline-powered vehicles. Thus, the study ignores the possibility that fuel efficiency standards might motivate technological advancements that lower the implicit price of higher fuel efficiency.

And last, the analysis ignores public benefits of increasing fuel efficiency standards. Therefore, it is likely that these estimates represent a substantial upper-bound on the implicit cost of raising fuel efficiency.

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SECOND ESSAY: THE PRIVATE BENEFITS AND SOCIETAL IMPACTS OF ELECTRIC VEHICLES IN THE UNITED STATES

INTRODUCTION

US concerns about global warming and the nation's heavy reliance on oil, along with unstable gasoline prices, have motivated interest in the development and deployment of alternative fuels and new transportation technologies. One set of technologies under consideration are electric vehicles, including gasoline-powered hybrid and plug-in hybrid electric vehicles and battery electric vehicles (Romm 2006).

In the American Recovery and Reinvestment Act (ARRA) of 2009 (P.L. 111-5), the federal government established tax credits for the purchase of new light-duty electric vehicles. Also, as part of the Energy Independence and Security Act of 2007 (EISA 2007), the Department of Energy (DOE) provides both grants and direct loans to support the development of such vehicles. Moreover, according to a recently proposed joint rule by the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA), eligible electric vehicles would get extra corporate average fuel economy (CAFE) compliance credits, meaning that they would count as more than one vehicle when annual fleet fuel efficiency averages are calculated (Federal Register 2009). The question is whether these policies and regulatory efforts are justified from a societal perspective given the benefits that results from the development and deployment of electric vehicles.

There is no doubt that relative to conventional gasoline-powered vehicles (CVs), electric vehicles will provide several societal benefits (Romm 2006; EPRI and NRDC 2007; Kromer and Heywood 2007; Bandivadekar, Cheah et al. 2008; Samaras and Meisterling 2008; Stephan and Sullivan 2008; Bradley and Frank 2009). Electric vehicles can play a role in decreasing transportation-related oil consumption by using electricity as a transportation fuel. Depending on the source of the electric power, they are likely to reduce greenhouse gas (GHG) emissions and criteria air pollutants. Reducing oil consumption, criteria pollutants, and GHG emissions are all widely accepted as indicators of sustainability in the transportation sector (Jeon and Amekudzi 2005).

Researchers have sought to quantify some aspects of the societal benefits of electric vehicles through demonstration and simulation projects. Bradley and Frank (2009) provide a literature review of these studies. In one such study, Simpson(2006) examines the impacts of plug-in hybrid electric vehicle (PHEVs) and hybrid electric vehicles (HEVs) on gasoline consumption and finds that relative to a CV, a HEV would reduce gasoline consumption by 20% to 28%, and that a PHEV with more than 20 miles in all-electric range would reduce gasoline consumption by at least 45%[3].

With a different set of assumptions[4], Kliesch and Langer (2006) estimated that relative to a HEV, an average driver saves one-third on gasoline consumption when driving a PHEV-20 and 50% when driving a PHEV-40. They also studied the impacts of PHEVs on emissions and found that relative to a HEV and under the US average electricity generation mix, a PHEV-40 would reduce CO2 emission by 15% and NOx emission by 23% and would increase SOx emissions by 157%[5]. They found that the emission reduction benefits are larger in areas with electricity generation portfolios that are less carbon-intensive.

In collaboration with the Natural Resources Defense Council (NRDC), the Electric Power Research Institute (EPRI) estimated the nationwide long-term GHG emissions impacts of a large-scale adoption of PHEVs under different PHEVs adoption and electricity generation scenarios, and found significant GHG reductions compared to CVs and

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[3] Simpson (2006) assumes that PHEVs are fully-charged each day; Vehicles are driven 15,000 miles per year; For a PHEV-20, 28% of daily VMT is on electricity, and that this number is 40%, 50%, and 60% for a PHEV-30, -40, and -60, respectively.

[4] Kliesch and Langer (2006) assume that a PHEV-40 is fully-charged each day, and that it is driven 50% of the daily travel on electricity.

[5] Ibid.

HEVs (EPRI and NRDC 2007)[6]. In another study, Samaras and Meisterling (2008) assessed the life cycle GHG emissions from PHEVs and found that, under the current US average electricity generation mix, PHEVs reduce GHG emissions by 32% relative to CVs, but result in insignificant reductions compared to HEVs[7].

And finally, Stephan and Sullivan (2008) studied the environmental and energy implications of charging a significant number of PHEVs from the grid. They found that when operating in a charge-depleting mode, PHEVs would reduce CO2 emissions by 25% relative to HEVs when using current electricity generation capacity at night and up to 50% in the long term, when extra base load capacity is added[8].

But would an average vehicle purchaser be interested in purchasing and utilizing an electric vehicle instead of a CV? The answer is positive only if the private benefits that result from such a purchase would outweigh the premium the vehicle purchaser would have to pay to own the technology. From a vehicle purchaser’s perspective, the main benefit is the money saved on fuel. At current gasoline and electricity prices, $0.10 per kWh and $2.5 per gallon, driving a mile on electricity is cheaper than driving a mile on

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[6] EPRI and NRDC (2007) assume three electricity generation cases that are specified by their carbon intensity. The medium electricity generation scenario assumes that the total annual electric sector emissions decline by 41% between 2010 and 2050; Authors assume PHEVs will be introduced in 2010 and will reach maximum new vehicle market share by 2050. Three adoption scenarios are specified as a function of PHEVs maximum new vehicle market share. The medium adoption scenario assumes PHEVs achieve a 62% market share in 2050; It is assumed that vehicles are driven 12,000 miles a year.

[7] Samaras and Meisterling (2008) assume that the useful life of a vehicle is 150,000 miles; CV fuel efficiency is 30 mpg; HEV fuel efficiency is 45 mpg; PHEV fuel efficiency is 45 mpg in charge-sustaining mode and 3.2 miles per kWh in charge-depleting mode; PHEVs are fully-charged once per day; Electricity powers between 47% to 76% of VMT for different PHEV configurations.

[8] Stephan and Sullivan (2008) assume that the average fuel efficiency being displaced by PHEVs is 18.6 mpg; Fuel efficiency of PHEV in charge-depleting mode is 2.4 miles per kWh; Vehicles are driven 14,300 miles per year or 39 miles per day.

gasoline (2.5 cents per mile compared to 10 cents per mile[9]). Obviously, the magnitude of this benefit depends, among other things, on the consumers' driving and fueling patterns, as well as the price of electricity relative to that of gasoline, and the all-electric driving range of the vehicle[10].

However, the fuel cost savings come at a cost. Vehicle purchasers need to pay a premium to own the technology. Electric vehicles are expected to cost several thousand dollars more than similar-sized CVs, mainly because of the cost of high-capacity batteries (Lipman and Delucchi 2006; Simpson 2006; NAS 2009). Currently the cost estimates for batteries vary significantly ($2,000 to $30,000), depending on the market penetration rate, the all-electric range of the PHEV, and the battery technology (Kliesch and Langer 2006; Kalhammer, Kopf et al. 2007).

In this paper, I study the private benefits and societal impacts of replacing a CV with one of the following electric vehicle technologies: a conventional gasoline-powered HEV, a gasoline-powered PHEV and a battery electric vehicle (BEV). Quantifying the actual benefits and costs of driving an electric vehicle instead of a similar-sized CV over the vehicle's life is challenging, but useful in understanding the gap between private and societal interests. It constitutes vital information for policy makers and helps them better align the private interests with the public ones in order to improve social welfare.

In this study, I contribute to the electric vehicle literature by simultaneously estimating the fuel cost savings and changes in private surplus from the vehicle owner's perspective as well as changes in various externalities that result from driving an electric vehicle instead of a similar-sized CV, including changes in GHG

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[9] Assuming the efficiency of the electric motor is 4 miles per kWh and that of the gasoline engine is 25 miles per gallon.

[10] In a PHEV-X and BEV-X, X is the all-electric-range. The all-electric-range is the distance the vehicle can drive on electricity stored in its onboard battery, when the battery is fully charged.

emissions, criteria air pollutants, gasoline consumption, and congestion, from a societal perspective. I present the results in both physical and monetary terms.

I model the driving behavior of a vehicle owner that drives a CV, HEV, PHEV, and BEV as a function of the average cost of driving each technology for a mile and as a function of the amount of vehicle miles traveled (VMT), represented by distributions constructed from the National Household Travel Survey (NHTS). To my knowledge, no previous study has modeled the driving behavior to this level of detail. Also, I use a large set of input factors (e.g. energy prices, the way in which the future is discounted, consumer driving patterns, and the price elasticity of travel demand) and recent data on the values these factors could take and conduct a thorough sensitivity analysis to determine how changes in the values of the input factors affect the outcomes of interest. Specifically, I answer the following questions in this study:

- What is the magnitude of the fuel cost savings and changes in private surplus over the life of the vehicle, if a hypothetical vehicle purchaser buys and operates an electric vehicle instead of a similar-sized CV?
- What is the effect on several externalities of driving including GHG emissions and criteria air pollutants, gasoline consumption and congestion, if a hypothetical vehicle purchaser buys and operates an electric vehicle instead of a similar-sized CV?
- What are the policy implications of the findings?

This paper is organized as follows. In the following section I explain the technologies considered in this study. This is followed by a discussion of the approach, in which I explain the model and its parameterization. Next, I present the nominal case results and the results from the sensitivity analysis. I conclude the paper with a discussion of the policy implications of the findings, research caveats, potential future work, and conclusions.

VEHICLE TECHNOLOGIES UNDER CONSIDERATION

This study compares three electric vehicle technologies with a similar-sized conventional gasoline-powered vehicle with internal combustion engine, the type that dominates the current light-duty vehicle market. These electric-vehicle technologies are HEVS, PHEVs and BEVs.

HEVs, like the Toyota Prius, combine an internal combustion engine with a battery-electric motor. There are two types of HEV: series and parallel. In series HEVs the electric motor propels the vehicle, while the internal combustion engine is connected to a generator that powers the motor and recharges the batteries. In parallel HEVs, similar to CVs, the internal combustion engine supplies power to move the wheels. However, the kinetic energy, which is usually wasted during braking, is turned into electricity and stored in a battery. The stored energy in the battery is used by the electric motor to assist the internal combustion engine when accelerating, climbing, and driving at low speeds (Yacobucci 2007). HEVs are more efficient than CVs, mainly because they have a smaller engine and a regenerative brake[11].

PHEVs are vehicles equipped with an internal combustion engine and an electric motor with a high-capacity battery pack that can be recharged from an off-board source (i.e. by plugging into a standard power outlet). When the battery is charged, the vehicle can run on the stored electricity. Once the stored electricity is consumed, the vehicle will operate in a conventional HEV mode, until recharged (Yacobucci 2007; Bradley and Frank 2009). Few models (e.g the Chevy Volt by General Motors with an all-electric range of 40 miles and the Plug-in hybrid Prius by Toyota with an all-electric range of 13 miles) are scheduled to be introduced into the market by late 2010 (Maynard 2008; Terlep 2009; Toyota USA Newsroom 2009).

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[11] An energy recovery mechanism that converts some of the kinetic energy of the vehicle into electricity when braking

Larger batteries allow PHEVs to be driven on electricity for longer distances. The distance to which the fully-charged on-board battery is able to power the vehicle on electricity alone is called the all-electric range of the vehicle. Three all-electric ranges are considered in this study: an all-electric-range of 20 miles (PHEV-20), 40 miles (PHEV-40), and 60 miles (PHEV-60).

The fully-charged PHEV modeled in this study will drive in a charge-depleting mode until the battery is depleted to a minimum state-of-charge (SOC) threshold, then revert to a conventional HEV mode (also called charge-sustaining mode), until recharged.

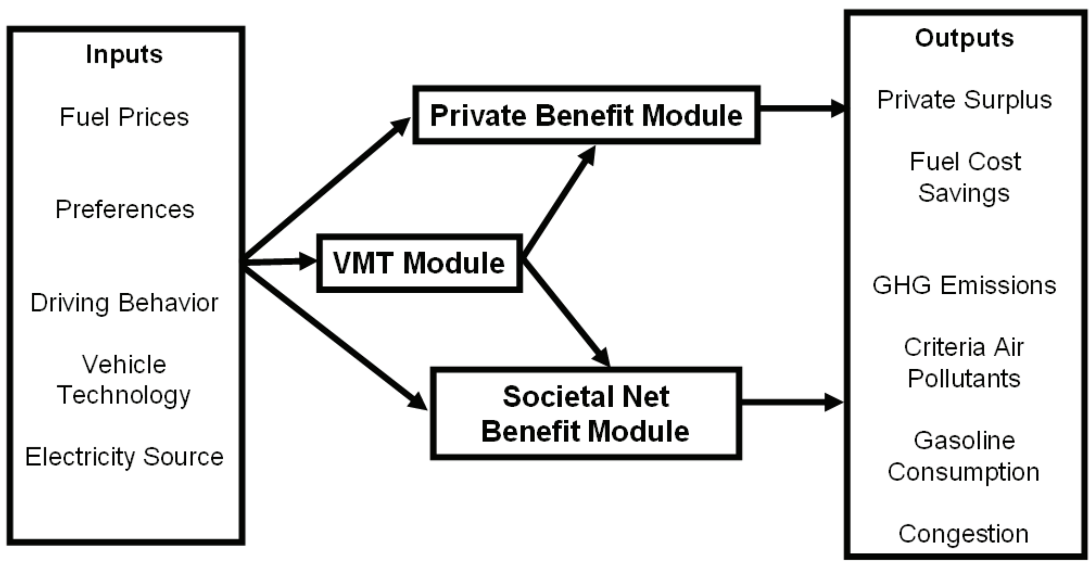
BEVs operate entirely on electricity stored in high-energy battery pack charged by an off-board source. The electric energy from batteries is delivered to the electric motor and motor controller that use the electricity to produce mechanical energy and propel the vehicle. When fully charged, a BEV can be driven a certain range on electricity. Once the battery is depleted, the vehicle needs to be recharged. The range limitation of BEVs is one of the main obstacles to their success. PHEVs combines the benefits of HEVs and BEVs as they provide the driver with the choice of driving a portion of the travel on electricity while eliminating the range-limit concerns of BEVs (Bradley and Frank 2009).

The success of each of these electric-vehicle technologies depends on the development of a battery technology that has low-cost and is durable and that can provide a large all-electric driving range. The battery technology under consideration by industry is lithium ion, which is suggested by the literature to be the most promising in electric-vehicle applications (Karden, Ploumen et al. 2007; Axsen 2008).

APPROACH

The private benefits and societal impacts of replacing a CV with an electric vehicle will vary because of many factors. Among others, these include relative changes in the price of gasoline and electricity, the way in which the future is discounted, consumers driving patterns, and fuel efficiencies of the CV that is being replaced by the electric vehicle. To simulate the influence of these factors on the private benefits and societal impacts, I develop a spreadsheet model shown schematically in Figure 2.1. The input parameters reflect different assumptions about key factors mentioned above. The outputs of interest include fuel cost savings and changes in private surplus, GHG emissions, criteria pollutants and gasoline consumption and the driver's contribution to congestion.

Figure 2.1: Schematic Representation of the Spreadsheet Model



In this section, I describe the simulation model. This model has three modules: the Vehicle Miles Traveled (VMT) module, the Private Benefit module, and the Societal Net Benefit module. The VMT module is an intermediate module which passes information on driving behavior to the Private Benefit and the Societal Net Benefit modules. Each of these modules is introduced below.

VMT Module

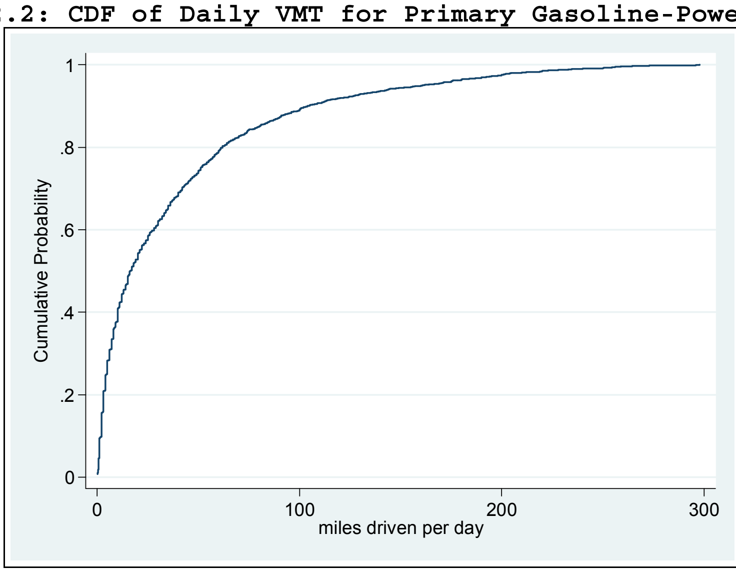
The literature either assumes that PHEVs are driven a fixed percentage of a fixed annual VMT on electricity (for examples see Simpson (2006), Duvall and Knipping (2007), Samaras and Meisterling (2008)), or estimates the fraction of the time the average driver would drive on electricity when operating a PHEV of a given all-electric range using national level data (Kliesch and Langer 2006).

These assumptions might work when estimating the costs and benefits of adopting a significant number of PHEVs in aggregate, but are not appropriate for per vehicle cost-benefit analysis given that driving patterns vary widely and the share of gasoline and electricity used to power PHEVs will vary considerably with the distance driven between vehicle recharges.

In this study, I refrain from this common assumption. Instead, using the National Household Travel Survey (NHTS) data (DOT 2001), I construct the cumulative distribution function (CDF) of daily VMT for gasoline-powered conventional passenger cars (Figure 2.2). For electric vehicles, I adjust this distribution using a technique I describe shortly which respects the fact that as the cost of driving per mile changes, so will the amount of driving that households will tend to engage in.

The base case VMT distribution is calculated for households that utilize their primary vehicle between 10,000 and 17,000 miles per year. I also calculate this distribution for households that utilize their primary vehicle less than 10,000 miles per year and more than 17,000 miles per year. In so doing, I am able to capture the likely benefits and impacts that accrue when the PHEV is utilized to a greater or lesser extent each year.

Figure 2.2: CDF of Daily VMT for Primary Gasoline-Powered Vehicles



For analytical purposes, I approximate the empirical VMT CDF with a discrete distribution that consists of 20 blocks, each representing 5 percent of the distribution. The VMT value associated with the ith block (or quantile) is denoted $q_{t,k,i}$ where t = 0,1,… is an index on time or vehicle age, $k \in \{CV, HEV, PHEV, BEV\}$ is an index on vehicles type, and i=1,2,...,20 is an index on quantile of the daily VMT distribution. For example, $q_{5,CV,4}$ represents the 4th (or 20%)-quantile on the daily VMT CDF for a CV in year 5.

To model how households adjust their driving behavior as the cost of driving changes, I solve a system of equations which vary with gasoline and electricity prices, gasoline and electricity fuel efficiency, and the initial distribution of VMT calculated from the NHTS for CVs. In particular, I solve the following equations for the average daily VMT, $\overline{q}_{t,k}$ for each vehicle class k in year t.

Average Daily VMT Equation

The average daily VMT for vehicle type k in year t is calculated from the discrete VMT CDF as:

$$\overline{q}_{t,k} = \sum_{i=1}^{20} \frac{1}{20} q_{t,k,i} \tag{2.1}$$

Driving Behavior Equation

The average daily amount driven is assumed to vary with the average cost of driving a mile, $ac_{t,k}$, as follows:

$$\overline{q}_{t,k} = \overline{q}_{0,CV} \left(\frac{ac_{t,k}}{ac_{0,CV}} \right)^{\varepsilon} \tag{2.2}$$

where ε<0 is the price elasticity of travel demand.

Average Cost of Driving per Mile Equation

The average cost of driving is calculated as follows:

$$ac_{t,k} = \frac{1}{\overline{q}_{t,k}} \sum_{i=1}^{20} \frac{1}{20} c_{t,k}(q_{t,k,i}) \tag{2.3}$$

where $c_{t,k}(q)$ is the total private cost of driving at time t, for vehicle k which varies with the daily driving distance q. The function $c_{t,k}(q)$ is calculated as

$$c_{t,k,i}(q) = \begin{cases} q\dfrac{p_{t,G}}{\mu_k} & \text{if } k = \{CV, HEV\} \\ q\dfrac{p_{t,E}}{\lambda} & \text{if } k = \{PHEV, BEV\} \text{ and } q \le X \\ X\dfrac{p_{t,E}}{\lambda} + (q - X)\dfrac{p_{t,G}}{\mu_k} & \text{if } k = \{PHEV\} \text{ and } q > X \end{cases} \quad (2.4)$$

where $p_{t,G}$ is the price per gallon of gasoline at time t, $p_{t,E}$ is the price per kWh of electricity at time t, μ_k is the gasoline fuel efficiency (miles/gallon) of vehicle class k, λ is the efficiency of PHEVs running on electricity (miles/kWh), and X is the distance at which PHEVs can be driven on electricity before they must switch to gasoline.

Daily VMT Adjustment Equation

Finally, I assume that as average daily VMT changes, the distribution of daily VMT is shifted in and out according to the following equation:

$$q_{t,k,i} = q_{0,CV,i}\left(\frac{\bar{q}_{t,k} - \bar{q}_{0,CV}}{\bar{q}_{0,CV}}\right). \quad (2.5)$$

By scaling the distribution in this way, Equation 2.1 holds. I use an iterative procedure to solve the system of Equation 2.1 to Equation 2.5. The procedure iteratively seeks out values of $\bar{q}_{t,k}$ that cause all four equations to hold. The procedure is used to solve for $\bar{q}_{t,k}$ for all time periods, t, and vehicle types, k.

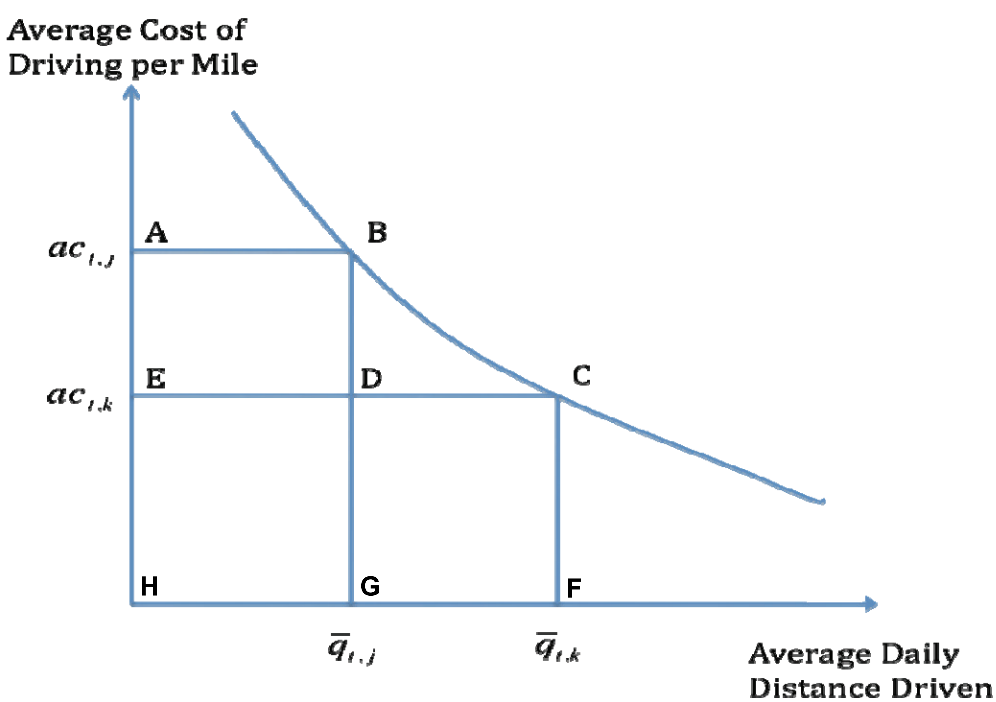
Private Benefit Module

From a private perspective, the main benefit of driving a more fuel-efficient vehicle is the reduction in the cost of driving. When the cost of driving decreases, vehicle purchasers benefit from lower total expenditures on fuel and any additional driving they engage in as a result of the cost reduction. Graphically, this can be shown in Figure 2.3 using the standard notion of private surplus in microeconomics. The curve shown in the figure represents the inverse demand for travel, where the demand for travel is determined by Equation 2.2. In the example, vehicle type k has a lower average cost of driving. The fuel cost savings without a change in driving behavior is calculated as the area ABDE. Because the cost of driving vehicle k is less than vehicle j, the households will tend to utilize the more efficient vehicle more. The benefit of this extra mobility is represented by the area under the inverse demand curve associated with the triangular area BCD. The sum of these two areas can be calculated as:

$$PS_{t,k,j} = 365 * \int_{ac_{t,k}}^{ac_{t,j}} \overline{q}_{0,CV} \left(\frac{z}{ac_{0,CV}} \right)^{\varepsilon} dz = \frac{365}{\varepsilon + 1} \frac{\overline{q}_{0,CV}}{\left(ac_{0,CV}\right)^{\varepsilon}} \left(\left(ac_{t,j}\right)^{\varepsilon+1} - \left(ac_{t,k}\right)^{\varepsilon+1} \right) \quad (2.6)$$

Here $PS_{t,k,j}$ represents the change in private surplus if the vehicle buyer purchases and utilizes vehicle k instead of vehicle j in year t. The change in fuel expenditures after accounting for change in driving behavior is calculated as the area ABGH minus area ECFH.

Figure 2.3: Private Benefits of Driving Vehicle Type k Relative to j



It is assumed that a new similar-sized HEV, PHEV, BEV and CV have similar service (e.g. maintenance, repair) and fixed (e.g. insurance) costs (MacLean and Lave 2003), and that the variable cost that is significantly different is their fuel costs. There is little data available at this time to study the validity of this assumption or to justify assuming otherwise. The fuel cost savings is a lower-bound estimate of the amount of the money a consumer is willing to pay extra to own an electric vehicle instead of a CV. This is because purchasers of fuel efficient vehicles, are also motivated by environmental preservation, oil independence promotion, embracing new technologies (Heffner, Kurani et al. 2007) and a reduction in volatility of cost of driving associated with fluctuating gasoline prices. These values are generally difficult to quantify and are not included in this study.

A final step required to quantify the consumer benefits over time of one vehicle type relative to another involves discounting and taking into account vehicle survival rates and utilization rates. Let s_t denote the probability that a vehicle is still operational in year t. Vehicles may stop being used because of a car crash or mechanical failure. In principle s_t will probably vary across vehicle types although little data exists at this point to justify using different survival rates for different vehicle types. The maximum lifespan of a vehicle is assumed to be 30 years. The weighted average lifespan of the vehicle, considering the survival probability, is about 16 years.

As an empirical fact, older vehicles tend to be used less frequently. To account for this, we assume that older vehicles are used fewer days per year than newer vehicles. In particular, let α_t represent the percentage of days a vehicle of age t is driven each year. Finally, in order to aggregate private benefits over time a discount rate of δ is used. The present discount value of the change in private surplus when the private buyer purchases and utilizes vehicle type k instead of j is therefore given as:

$$PVPS_{k,j} = \sum_{t=1}^{30} \left(\frac{1}{1+\delta}\right)^{t-1} s_t \alpha_t PS_{t,k,j} \qquad (7)$$

Societal Net Benefit Module

Driving results in various types of societal damage that are "external" to a driver's travelling decision (Delucchi 2000). In the Societal Net Benefit module I consider various externalities including changes in GHG emissions, criteria air pollutants, gasoline consumption and the driver's contribution to congestion. I estimate changes in these externalities when an electric vehicle displaces a similar-sized CV. Using estimates of the damage costs of the externalities from existing literature, I state the changes in monetary terms as well.

Greenhouse Gas Emissions

Reduction in GHG emissions[12] are an important societal benefit of driving more fuel-efficient vehicles. The Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) 1.8 Model, developed by the Argonne National Laboratory, is used to determine well-to-wheels[13] GHG emissions in grams of CO2-equivalent per mile for a similar-sized CV, HEV, and PHEV.

GREET 1.8 estimates upstream emissions from petroleum extraction, refining, and transportation, as well as use-phase emissions for each vehicle technology. GREET generates such data for 2010 to 2020. It is assumed that per mile GHG emissions produced remain the same after 2020.

GHG emissions from a PHEV is calculated assuming that it produces the same amount of GHG emissions as a HEV when operating in a charge-sustaining mode, and the same amount of GHG emissions as BEV when operating in a charge-depleting mode. The magnitude of GHG emissions reductions from PHEVs and BEVs depends on the source of

[12] GHGs considered are Carbon Dioxide (CO2), Methane (CH4), and Nitrous Oxide (N2O).

[13] Fuel cycle and use-phase emissions

electric power used to power these vehicles. The electricity may come from any mix of energy sources including coal, nuclear, and natural gas. In this study, the emissions are estimated for situations in which the a PHEV and BEV operates on electricity generated from the current average US electricity generation mix[14] as well as on electricity generated from natural gas combined cycle (NGCC), coal and nuclear plants.

The social benefits of displacing a CV with an electric vehicle with regard to GHG emissions are estimated as the difference between their corresponding GHG emissions. The GHG emissions produced during production, recycling and disposal of batteries are not considered in this study, but Samaras and Meisterling (2008) estimate that the GHG emissions associated with lithium-ion battery materials and production accounts for 2-5% of life cycle emissions from PHEVs.

Criteria Pollutants

Another outcome of interest from a societal perspective is the change in the amount of criteria air pollutants in urban areas. Criteria air pollutants are detrimental to human health. The effects can range from itchy eyes, to chronic respiratory problems to cardiovascular diseases (McCubbin and Delucchi 1999).

The GREET model is used to estimate well-to-wheel criteria pollutants, in grams per mile, for CVs, HEVs, and BEVs. GREET generates such data from 2010 to 2020. It is assumed that per mile criteria pollutants remain the same after 2020. The criteria air pollutants considered include Volatile Organic Compounds (VOC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), coarse Particulate Matters (PM10), fine Particulate Matters (PM2.5), and Sulfur Oxides (SOx). Criteria pollutants produced in urban areas are considered because these are the emissions that affect human health.

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[14] The average US electricity generation mix includes: coal (50.4%), nuclear power (20%), natural gas (18.3%), residual oil (1.1%), biomass electricity (0.7%), and others (9.5 %).

Here again, well-to-wheels criteria pollutants from an electric vehicle are estimated for situations in which it operates on electricity generated from the US average electricity generation mix as well as from natural gas combined cycle (NGCC), coal and nuclear plants. The social benefit of displacing a CV with an electric vehicle with regard to the criteria air pollutants is estimated as the difference between the amounts of criteria air pollutants generated over the life of the vehicle.

Congestion

Another outcome metric calculated in the Societal Net Benefit module is the driver's contribution to congestion. Change in this externality relative to a CV arises from the rebound effect. Increasing vehicle efficiency and partially replacing gasoline with electricity reduces the cost of driving, and induces consumers to drive more. This results in additional congestion *(Greening, Greene et al. 2000)*. Additional congestion results in additional injuries and extra time spent in traffic.

Using the elasticity of vehicle miles traveled with respect to fuel-cost per mile, I estimate the additional miles driven when the driver operates an electric vehicle instead of a similar-sized CV. I then use estimates of the damage costs of each additional mile of driving from the literature to express the societal cost of the additional miles in dollar values.

Benefits of Reduced Dependence on Gasoline Not Internalized by Consumers

Another important societal benefit considered is the effect on gasoline consumption. Displacing a CV with a similar-sized electric vehicle reduces the total gasoline consumed over the life of the vehicle, because a fraction of the gasoline is displaced by electricity.

From a societal perspective, saving gasoline is important at least for two reasons not already internalized by consumers: sustainability and energy security. From a sustainability perspective, it is crucial to take the welfare of future generations into account when consuming resources. Reducing gasoline consumption ensures that there is more gasoline left for future generations to enjoy. However, a large scale adoption of electric vehicles increases the consumption of another type of resource: lithium. Thus, the net sustainability benefit effect is unclear at this time.

From an energy security perspective, reducing gasoline consumption and diversifying fuel sources result in a transportation sector that is more robust to potential disruptions in oil supply or to spikes in gasoline prices (Toman 2002; Leiby 2007). However, it is not clear whether or not large-scale adoption of electric vehicles would result in another type of dependence: dependence on lithium instead of gasoline. The availability of lithium to a large extent depends on South America, especially Bolivia that contains more than half of the world lithium reserves, but does not produce anything at this time.

Andersson et al. (2001) estimate the extent to which lithium availability could constrain the diffusion of electric vehicles, and found that, there are sufficient lithium resources to support from 200 million to 12 billion BEVs by year 2100. A study by Meridian International Research (Tahil 2007), on the other hand is less optimistic and concludes that there are insufficient lithium resources to be used economically on a large scale by the auto industry, if the demand from other industries such as computers and cell phones are accounted for. Thus, the energy security argument might not be as valid in this case, especially given that lithium is available in few places around the world.

In this study, I estimate the amount of gasoline saved when a CV is displaced by a similar-sized electric vehicle. Using estimates from the literature on the energy security benefits of a gallon of gasoline saved, I express the societal benefit of a reduction in gasoline consumption in monetary terms as well.

Parameterization of the Model

Table 2.1 shows the set of input parameters and the numeric values used in the nominal case and in the sensitivity analysis to evaluate the outcomes of interest.

Table 2.1: Input Parameter Assumptions

Parameter (Unit)	Parameter Input Values		
	Low	Nominal	High
Fuel economy of CV (Miles/gallon)	18	24.1	35
Fuel economy of HEV (Miles/gallon)	-	50	-
Fuel economy in electric mode (Miles/kWh)	-	4	-
Price of gasoline ($/gallon)	1.5	2.5	4.5
Price of electricity ($/kWh)	0.06	0.1	0.25
Annual change in price of gasoline*	-0.01	1	+0.01
Annual change in price of electricity*	-0.01	1	+0.01
Discount Rate	3%	7%	10%
Price Elasticity of Travel Demand	-0.05	-0.15	-0.25
VMT Distribution	Low-mileage Distribution	Medium-mileage Distribution	High-mileage Distribution
Electricity Generation	Nuclear, NGCC	Average US	Coal

*relative to the price of other goods and services

According to EPA (2008), the average combined fuel economy of a gasoline-powered MY2008 conventional passenger car is 24.1 mpg[15], which is the value assumed for the CV fuel economy in the nominal case. In the sensitivity analysis, the combined fuel economy varies

[15] According to EPA, the calculation of combined fuel economy weights the city at 55 percent and the highway at 45 percent using the following equation:

$$FEcomb = 1 / ((0.55 / \text{city FE}) + (0.45 / \text{hwy FE}))$$

from 18 to 35 mpg. Also, among 2010 model hybrid vehicles listed on www.fueleconomy.com, the Toyota Prius has the best fuel economy rating (50 mpg). In this study, I assume the fuel economy of the hybrid is 50 mpg as well[16]. Following Kammen et al (2008), Lemoine et al (2008), and EPRI (EPRI and NRDC 2007), I assume that the fuel efficiency of a BEV and a PHEV when operating in a charge-depleting mode is 4 miles/kWh.

The retail gasoline price has increased from an average of $ 1.11 per gallon in the nineties to over $4 per gallon in 2008. The average gasoline price from 2000 is over $2 per gallon (EIA 2009). Thus, a nominal gasoline price of $2.5 per gallon is assumed for comparison. This value is also consistent with the average forecasted gasoline price by the 2009 Annual Energy Outlook (EIA 2009). In the sensitivity analysis it is assumed that the gasoline price varies from $1.5 to $4.5 per gallon.

According to 2009 Annual Energy Outlook, the average residential price of electricity in the US is expected to be 10 cents per kWh in 2010 (EIA 2009). Unlike the price of gasoline, the price of electricity is predicted to increase only slightly from 10 cents to 12 cents in 2030. However, the price varies significantly by region. In 2009, the electricity price ranged from 6.4 cents per kWh in Idaho to 25 cents per kWh in Hawaii (EIA 2009). In this study, I use the national residential average price of 10 cents per kWh as the nominal case value. In the sensitivity analysis, I assume the residential price of electricity ranges from 6 cents per kWh to 25 cents per kWh.

Also, in the nominal case, I assume that the prices of gasoline and electricity do not change relative to the prices of other goods and services. However, in the sensitivity analysis two other situations are considered: when the prices of gasoline and

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[16] Alternatively, as Greene et al (2004) suggest, I could have considered a conventional hybrid passenger vehicle to be about 40% more fuel-efficient than a compatible conventional gasoline-powered passenger vehicle Greene, D., K. Duleep, et al. (2004). Future potential of hybrid and diesel powertrains in the US light-duty vehicle market, United States. Dept. of Energy.

electricity increase, or decrease, relative to the prices of other goods and services.

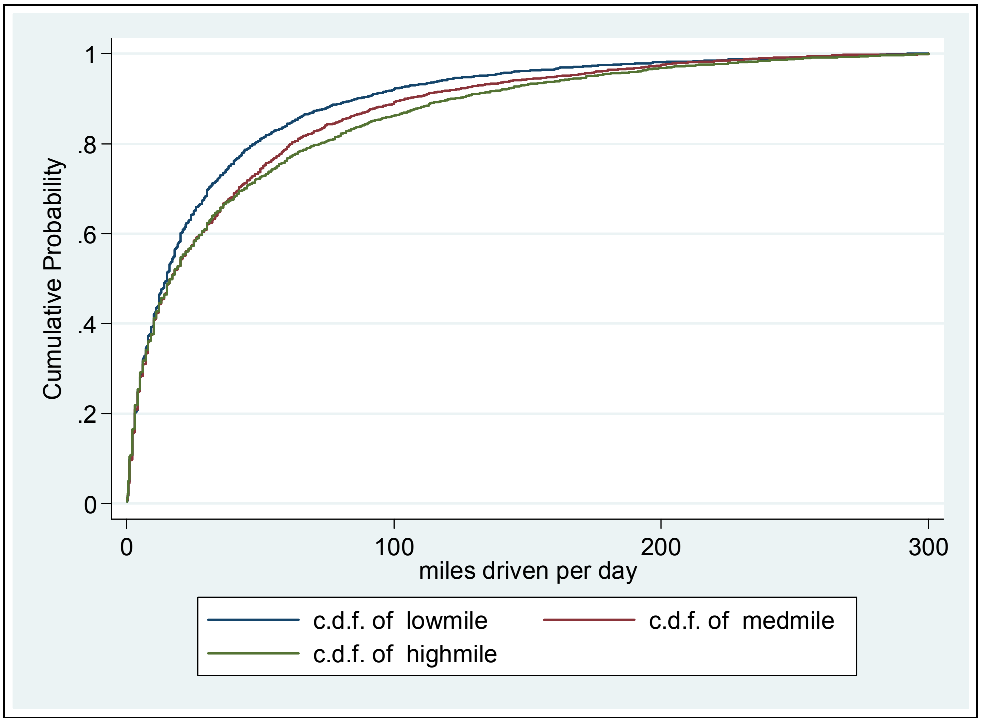
U.S. Office of Management and Budget (OMB) requires the use of 7 percent and 3 percent real discount rates to measure the present value of future benefits and costs for regulatory analysis . According to OMB, a 7 percent discount rate represents the private before-tax rate of return on capital and should be used as a base-case for regulatory analysis, and a 3 percent discount rate reflects the real rate of return on long-term government debt which is used to approximate the "social rate of time preference" (OMB 2003). OMB as well as NHTSA (2006) advise the use of higher discount rate in the context of purchasing decision for "energy-using durables", including passenger vehicles. In this study, the prevailing real discount rate considered in the base case is 7 percent. However, discount rates of 3 and 10 percent are also considered in the sensitivity analysis.

Improving the fuel efficiency of a vehicle reduces the costs of driving it a mile. This results in additional driving, which in turn translates into more fuel consumption. This concept is called the rebound effect (Greene, Kahn et al. 1999; Greening, Greene et al. 2000; Portney, Parry et al. 2002; Small and Van Dender 2007). Using the elasticity of vehicle miles traveled with respect to fuel-cost per mile, I estimate the additional miles driven when the driver operates an electric vehicle instead of a similar-sized CV.

Several studies have estimated the price elasticity of VMT (Mayo and Mathis 1988; Gately 1990; Greene, Kahn et al. 1999). Most estimates fall between -0.10 and -0.25 (Greening, Greene et al. 2000). In this study, the nominal price elasticity of travel demand is considered to be -0.15, but low and high values (-0.05 and -0.25) are also considered in the sensitivity analysis.

Merging NHTS Daily Trip and Vehicle data files (DOT 2001), VMT distributions are constructed for passenger cars that are driven less than 10,000 miles per year (low-mileage vehicles), between 10,000 and 17,000 miles per year (medium-mileage vehicles), and more than 17,000 miles a year (high-mileage vehicles) (Figure 2.4). The medium-mileage distribution is used in nominal calculations, and the other two in sensitivity analysis. For details see Appendix C.

Figure 2.4: Cumulative Distribution for Daily VMT for Passenger Cars



Vehicle survival rates (s_t),or the probability that a vehicle is still operational in year t, are taken from Davis et al (2009). Vehicle's utilization factor (α_t) is calculated from data on average annual miles per household vehicle by vehicle age in Davis et al (2009). Vehicles' utilization factors account for the empirical fact that vehicles are used less as they age. Refer to Appendix A for details on survival rates (s_t) and vehicles' utilization factor (α_t).

Also, since frequent deep cycle discharges— above 80% of the electricity stored in a fully-charged battery— deteriorate the battery's longevity (Kromer and Heywood 2007), in this study it is assumed that a PHEV consumes 80 percent of the energy stored in a fully-charged battery before using the gasoline-powered internal combustion engine.

The range limit of a BEV creates a disutility for the car buyer, because on days when the car buyer needs to drive the vehicle more than its electric range (assumed to be 200 miles), she needs to stop and charge her vehicle. To address this issue, it is assumed that the size of the disutility is equal to the cost of buying a mobile charger for road trips that exceed the electric range of the BEV. It is assumed that such a charger would take the form of the Universal Mobile Connector currently sold by Tesla Motors for $1,500. This charger can be stored in the trunk of the vehicle and can be plugged into regular outlets, if needed. Thus, when calculating the private benefits for the BEV, I consider an upfront cost of $1,500 to account for this disutility.

Note that this is not a perfect estimate of the disutility, since it does not take into account the fact that the driver needs to spend considerable time charging her vehicle. For example, the Universal Mobile Connector has a charge rate of 32 miles per hour (Tesla Motors no date). However, the disutility will decrease over time if a network of public charging facilities is built that allows the car buyer to charge her vehicle in an acceptable time.

In this study, the externalities are first expressed in physical units. Next, similar to Keefe et al (2008), the externalities are expressed in monetary terms using estimates of dollar damage costs of externalities from various studies.[17] Table 2.2 presents a comprehensive list of these damage costs. Recognizing the fact that assigning a single monetary value to a nonmarketable externality is controversial, a range of input values reported in the literature is considered in the sensitivity analysis. The enormity of the ranges shown in Table 2.2 indicates the great uncertainty we face as a

[17] For details on the estimation procedure for various social costs of motor-vehicle use refer to a series of 20 reports by Delucchi, M. (1996). The Annualized Social Cost of Motor-Vehicle Use, Based on 1990-1991 Data. Davis, CA, University of California, Institute of Transportation Studies.

society when it comes to understanding the links between emissions, impacts, and economic values.

Table 2.2: Damage Costs of Externalities ($2009)

Type of Externality	Damage Cost Unit	Input values for damage cost		
		Low	Nominal	High
GHGs emissions	$/ton Co2-equivalent	1.5	14	70
VOC emissions	$/ton	210	1,090	1,980
CO emissions	$/ton	20	90	160
NOx emissions	$/ton	1,710	6,350	10,740
PM10 emissions	$/ton	11,430	20,260	29,100
PM2.5 emissions	$/ton	21,630	173,860	326,100
SOx emissions	$/ton	6,980	31,490	56,000
Energy Security	$/gallon	0.02	0.37	0.63
Congestion	$/mile	0.02	0.035	0.09

*Damage costs are adjusted to 2009 dollars (Bureau of Labor Statistics no date)

To monetize the social cost of GHG emissions, estimates of the damage costs of carbon dioxide were taken from Tol (2005), who examines various peer-reviewed studies that estimate the damage cost of carbon dioxide emissions. Combining the findings of these studies, he concludes that the mode of the estimated damage cost is $1.5, the mean is $14, and the 95th percentile is $70 per ton of CO2-equivalent[18].

Similar to the NHTSA (2006) study, damage cost estimates for criteria air pollutants were derived from OMB (2004) and McCubbin and Delucchi (1999), and were adjusted to 2009 dollars. Note that in cases where only a range is reported for the damage costs, the average is taken as the damage cost for the nominal case.

Leiby (2007) estimates the incremental societal benefits of reducing US gasoline imports to range from $0.18 to $0.63 per gallon, with the mean value of $0.37 per gallon. A National Research Council

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[18] Original damage costs were reported in $/ton of carbon. Using conversion factors from EPA (http://www.epa.gov/OMS/climate/420f05002.htm) the unites were converted to $/ ton of CO2-equivalent

(2002) study reports a range from $ 0.02 to $ 0.24 per gallon. Thus, a range of $0.02 to $0.63 per gallon is considered in this study for the implicit valuation of energy security gains. However, note that these values exclude benefits gained from being more sustainable using scarce resources and from diversifying transportation fuels. Also, note that some of the energy security gains might be partially offset by potential lithium security concerns.

Additional VMT that result from improved fuel efficiency lead to several societal costs that are not internalized by the driver. All else equal, an extra mile driven increases the likelihood that others will be involved in a collision, creates additional noise, and results in delays inflicted on others. Added congestion would increase the likelihood of a collision, but it would also induce people to drive slower or more carefully. This would result in more frequent accidents, but less severe ones (Parry, Walls et al. 2007). Thus, similar to Mayeres et al. (1996) and FHWA(1997), I assume the external crash cost of an extra mile of driving is negligible.

As stated in Delucchi and Hsu (1998), the cost of noise from an additional mile of vehicle travel depends on the type of vehicle and the type of driving added. Since, an electric vehicle is less noisy than a CV, in this study I assume that the damage cost of noise from driving an electric vehicle an extra mile is negligible. Thus, the congestion damage costs considered in this study reflect the value of added travel time inflicted on others.

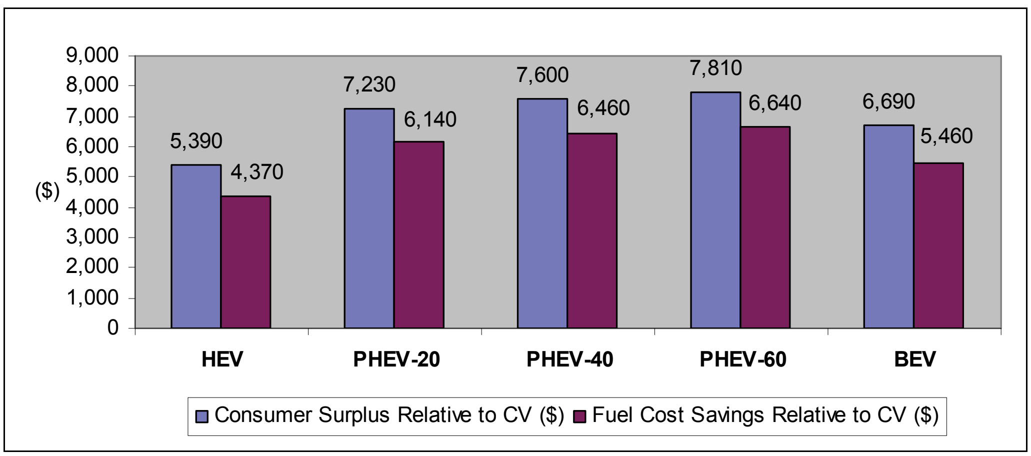
Delucchi(1998) estimates the damage cost of added delays inflicted on others to range from 2 cents per mile in a low-cost case to 9 cents per mile in a high-cost case. Using Delucchi’s (1998) estimates, I assume congestion damage cost ranges from 2 cents per mile to 9 cents per mile. I assume a nominal value of 3.5 cents per mile which is consistent with that considered in Parry et al. (2007).

RESULTS

Private Perspective

Under the nominal assumptions, the present value (PV) of the fuel cost savings from replacing a CV with a similar-sized HEV, PHEV-20, PHEV-40, PHEV-60, and BEV over the life of the vehicle are $4,370, $6,140, $6,460, and $5,460, respectively; and the PV of the change in private surplus are $5,390, $7,230, $7,600, $7,810, and $6,690 respectively (Figure 2.5). The private surplus gains are slightly higher than the fuel cost savings, since they account for the mobility benefit gained from the improved fuel efficiency as well.

Figure 2.5: Private Benefits Relative to CV (PV, $2009)



Societal Perspective

Criteria Air Pollutant and GHG Emissions

When the electricity generation mix is the US average, if a CV is displaced by an electric vehicle, the GHG emissions as well as all the criteria pollutants, except for SOx, would decrease (Table 2.3). However, changes in GHG emissions are negligible when a PHEV or a BEV is purchased and used instead of a HEV (Table 2.4).

Table 2.3: Change in GHG Emissions and Criteria Air Pollutants Relative to a CV under Nominal Case (%)

Type of Criteria Pollutant	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
VOC	-18%	-39%	-53%	-64%	-99%
CO	16%	-15%	-35%	-50%	-99%
NOx	-9%	-17%	-22%	-25%	-39%
PM10	6%	-1%	-5%	-9%	-21%
PM2.5	5%	-7%	-15%	-21%	-41%
SOx	-17%	62%	113%	152%	272%
GHG	-17%	-16%	-16%	-15%	-15%

Table 2.4: Change in GHG Emissions and Criteria Air Pollutants Relative to a HEV under Nominal Case (%)

Type of Criteria Pollutant	PHEV-20	PHEV-40	PHEV-60	BEV
VOC	-27%	-43%	-56%	-99%
CO	-27%	-44%	-57%	-99%
NOx	-9%	-14%	-18%	-33%
PM10	-7%	-11%	-14%	-26%
PM2.5	-12%	-19%	-25%	-44%
SOx	96%	157%	204%	349%
GHG	1%	2%	2%	2%

These findings differ to some extent from those of Kliesch and Langer (2006). They estimated that relative to a HEV and under the US average electricity generation mix, a PHEV-40 would reduce CO2 emissions by 15% and NOx emissions by 23%, and would increase SOx emissions by 157%[19]. My estimates show that under the US average electricity generation mix, a PHEV-40 would actually slightly increase GHG emissions relative to a HEV. These differences result because of the different assumptions. For example, Kliesch and Langer (2006) assume that a PHEV-40 is driven 50% of its daily travel on electricity; whereas in this study, I model consumer driving patterns in more detail. Under the nominal assumptions, I estimate that a PHEV-40 is driven 46% of the time on electricity. Also, Kliesh and Langer (2006) do not take into account the rebound effect and that a

[19] Kliesch and Langer (2006) assume: vehicle is fully-charged each day; a PHEV-40 is driven 50% of the daily travel on electricity;

PHEV-40 is driven slightly more than a HEV due to a decrease in the marginal cost of driving.

Samaras and Meisterling (2008) have also found insignificant reduction in GHG emissions when a PHEV, running on electricity from the average US electricity generation mix, displaces a HEV. However, they found that under the current average US electricity generation mix, PHEVs reduce lifecycle GHG emissions by 32% relative to CVs, which is twice as much as my estimate (16% reduction in GHGs relative to CV). Differences in results are explained by the fact that Samaras and Meisterling do not account for the rebound effect[20]. To show this, I ran the model assuming that the demand for VMT is inelastic to the marginal price of driving. The results are presented in Table 2.5. As shown in this table, without the rebound effect, the results are similar to that of previous studies.

Table 2.5: Change in GHG Emissions and Criteria Air Pollutants Relative to a CV Assuming VMT Demand Price Elasticity is Zero (%)

Type of Criteria Pollutant	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
VOC	-29%	-52%	-65%	-75%	-99%
CO	0%	-32%	-52%	-66%	-99%
NOx	-22%	-31%	-37%	-41%	-50%
PM10	-9%	-18%	-23%	-27%	-36%
PM2.5	-9%	-23%	-32%	-38%	-52%
SOx	-29%	45%	91%	123%	201%
GHG	-28%	-29%	-30%	-31%	-32%

Gasoline Consumption and Congestion

Under the nominal assumptions, I estimate that gasoline consumption is reduced by 44%, 59%, 69%, 76%, and close to 100% if a CV is displaced by a similar-sized HEV, PHEV-20, PHEV-40, PHEV-60, and BEV, respectively. These translate into thousands of gallons of

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[20] Samaras and Meisterling (2008) assume that the useful life of a vehicle is 150,000 miles; the CV fuel efficiency is 30 mpg; the HEV fuel efficiency is 45 mpg; the PHEV fuel efficiency is 45 mpg in charge-sustaining mode and 3.2 miles per kWh in charge-depleting mode; and that the electricity powers between 47% to 76% of VMT for different PHEV configurations.

gasoline saved over the lifetime of the vehicle (2,770, 3,720, 4,330, 4,790, and 6,300 gallons, respectively).

These estimates are higher than those reported in Simpson(2006). Simpson(2006) studied the impact of PHEVs and HEVs on gasoline consumption and found that relative to CVs, HEVs would reduce gasoline consumption by 20% to 28%, and that PHEVs with more than 20 miles in all-electric ranges would reduce gasoline consumption by at least 45%. Note that Simpson(2006) assumes vehicles are driven 15,000 miles per year; and that a PHEV-20, PHEV-40, and PHEV-60 is driven 28%, 40% and 60% of daily VMT on electricity, respectively.

Under the nominal case, I estimate that gasoline consumption is reduced by 27%, 44%, and 57% if a HEV is displaced by a similar-sized PHEV-20, PHEV-40, and PHEV-60, respectively. These findings are similar to those of Kliesch and Langer (2006). They estimate that relative to a HEV, an average driver saves one-third on gasoline consumption when driving a PHEV-20 and 50% when driving a PHEV-40. Also, I estimate that due to improved fuel efficiency, under the nominal assumptions, a HEV is driven 24,470 miles more than a similar-sized CV over its lifetime. This number is 28,210, 31,060, 32,760, and 36,120 additional miles for a PHEV-20, PHEV-40, PHEV-60, and BEV, respectively.

Monetization of Externalities

As stated before, outputs are also expressed in monetary values. Table 2.6 presents the net present value (NPV) of the societal benefits that result from displacing a CV with a similar-sized electric vehicle. Under nominal assumptions, the NPV of the external benefits of displacing a CV with an electric vehicle, which are the benefits that are not internalized by the vehicle owner, are less than $700 per vehicle type over the lifetime of the vehicle.

Table 2.6: Societal Benefits Relative to CV (NPV, $2009)

Benefit /Cost Type	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
A: Change in private Surplus	5,390	7,230	7,600	7,810	6,690
B: Criteria Pollutants Reduction Benefit	10	-30	-50	-70	-110
C: GHGs Reduction Benefit	100	90	90	90	80
D: Energy Security Benefit	650	870	1,010	1,120	1,470
E: Congestion Cost	-540	-620	-680	-720	-800
F: Net External Benefit (B+C+D+E)	220	310	370	420	640
Net Societal (F+A)	5,610	7,540	7,970	8,230	7,330

SENSITIVITY ANALYSIS

In this section I explore the sensitivity of the results reported in the previous section to the input parameters' assumed values. I calculate the sensitivities of the outcomes of interest relative to the nominal by changing each parameter's value from its nominal value to its low or high value, keeping all other parameters at their nominal values[21]. Note that only selected results of the sensitivity analysis are presented in this section. For complete results refer to Appendix D.

Private Surplus and Fuel Cost Savings

I estimate that the PV of the change in private surplus from displacing a CV with a similar-sized PHEV-20 could be as little as $3,600 to as much as $14,490. My nominal case estimate is $7,230 (Table 2.7). The PV of the fuel cost savings is slightly lower and

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[21] $\psi_{\beta,l} = (\frac{\beta_l}{\beta_n} - 1) * 100$ where β =each outcome of interest; l =each parameter; $\psi_{\beta,l}$ =sensitivity of β to the value of l (in percentage); β_l =value of β given all parameters except l are at their nominal values ; β_n =value of β given all parameters are at their nominal values.

ranges form $3,060 to $12,310, with a nominal value of $6,140 (Table 2.8).

Table 2.7: Minimum, Maximum, and Nominal Change in Private Surplus Relative to CV (PV, $2009)

Size of change	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
Minimum	2,100 (1)	3,600 (3)	3,670 (3)	3,710 (3)	2,280 (3)
Nominal	5,390	7,230	7,600	7,810	6,690
Maximum	9,700 (2)	14,490 (2)	15,500 (2)	16,070 (2)	15,700 (2)

(1) Results when the fuel efficiency of the CV is 35 mpg
(2) Results when the price of gasoline is 4.5 $/gallon
(3) Results when the price of gasoline is 1.5 $/gallon

Table 2.8: Minimum, Maximum, and Nominal Fuel Cost Savings Relative to CV (PV, $2009)

Size of Savings	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
Minimum	1,740 (1)	3,060 (3)	3,120 (3)	3,150 (3)	1,710 (3)
Nominal	4,370	6,140	6,460	6,640	5,460
Maximum	7,860 (2)	12,310 (2)	13,170 (2)	13,650 (2)	13,120 (2)

(1) Results when the fuel efficiency of the CV is 35 mpg
(2) Results when the price of gasoline is 4.5 $/gallon
(3) Results when the price of gasoline is 1.5 $/gallon

The wide range is due to uncertainty regarding the energy prices and due to differences in driving patterns, the discount rate, and the fuel efficiency of the CV being displaced by the PHEV (Figure 2.6-2.10). The fuel cost savings follow a similar path. For details see sensitivity analysis results in Appendix D.

Figure 2.6: The Change in Private Surplus under Different CV Fuel Efficiencies (PV, $2009)

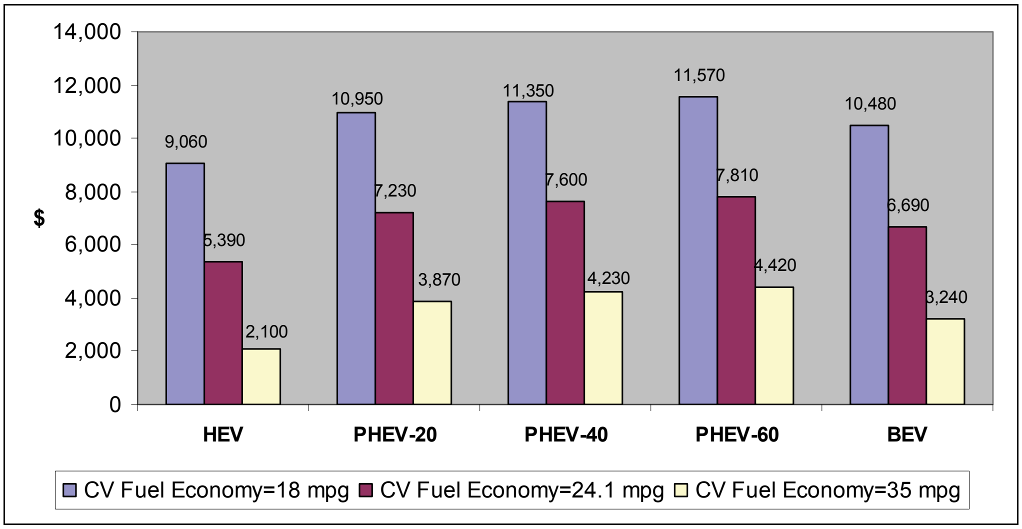


Figure 2.7: The Change in Private Surplus under Different Gasoline Prices (PV, $2009)

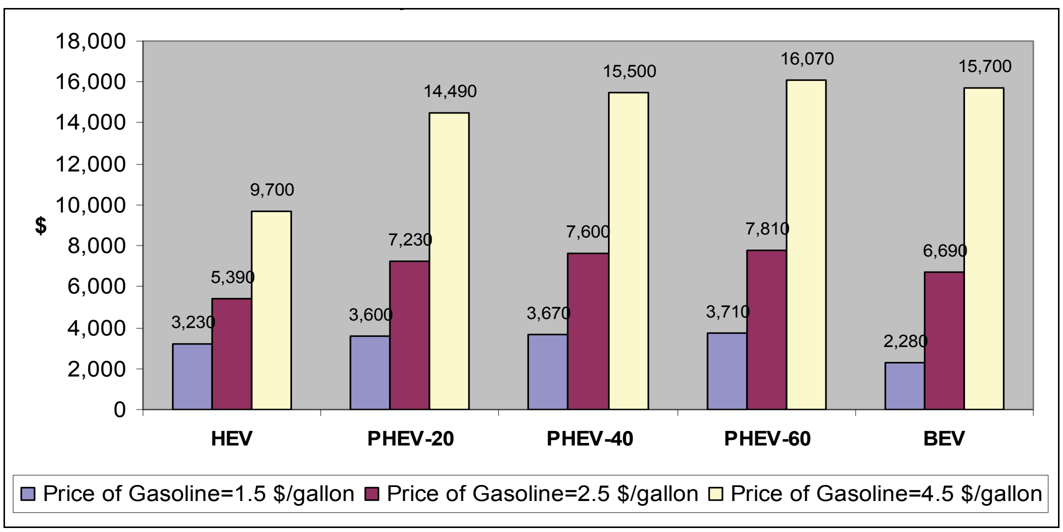


Figure 2.8: The Change in Private Surplus under Different Electricity Prices (PV, $2009)

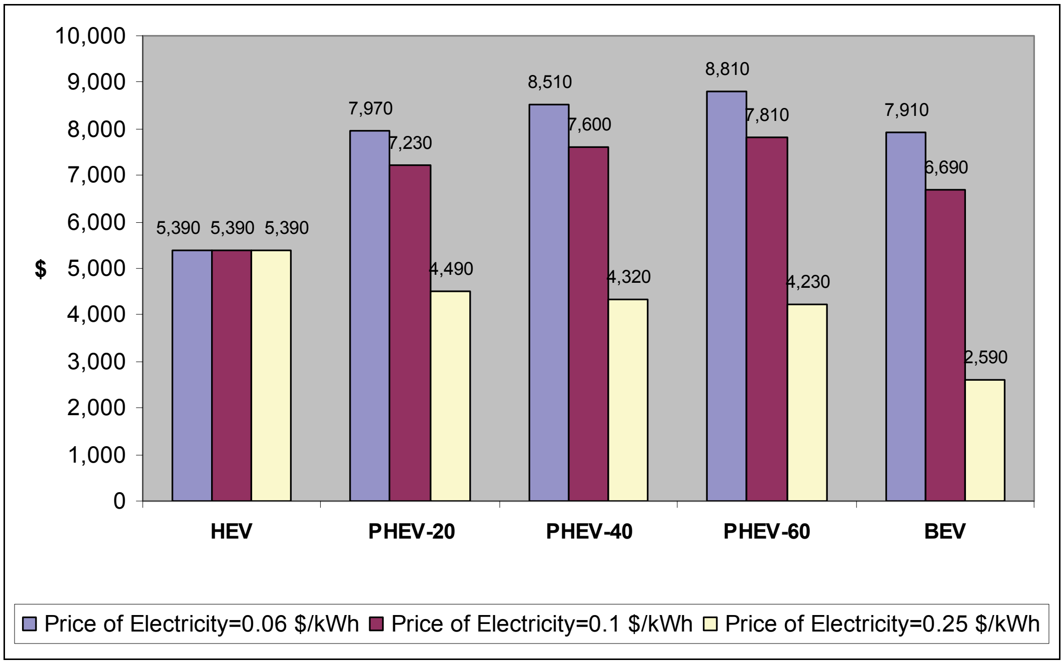


Figure 2.9: The Change in Private Surplus under Different Discount Rates (PV, $2009)

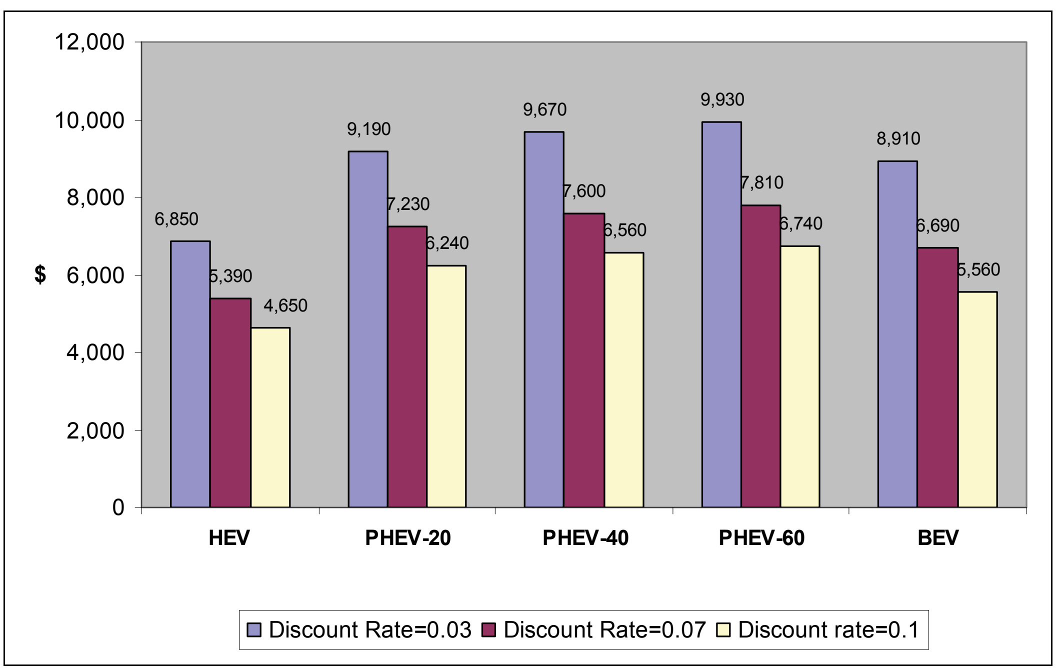
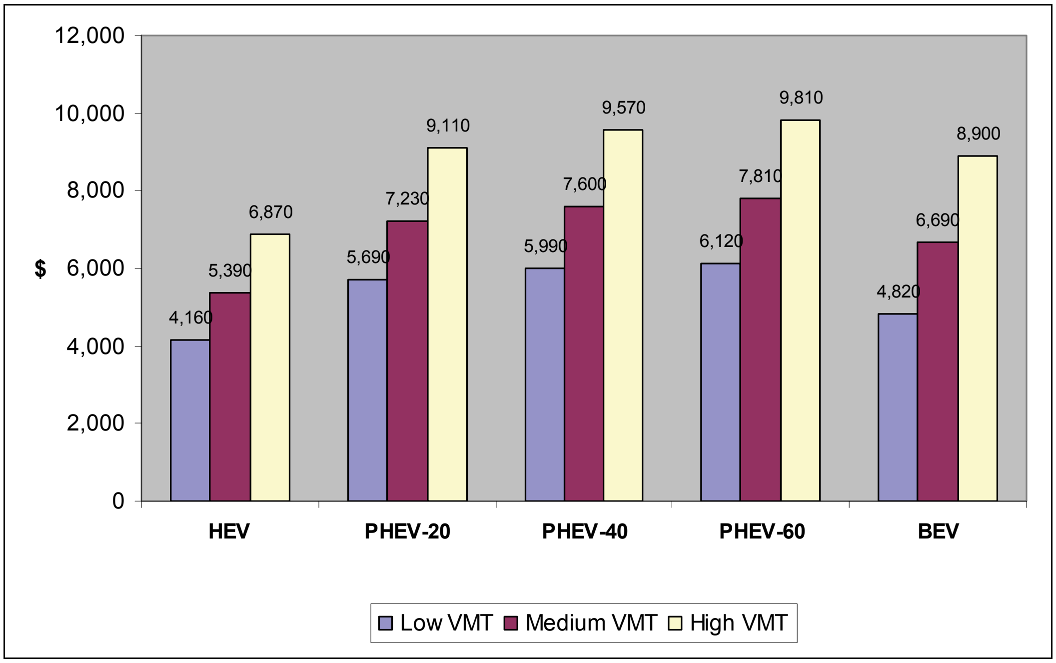


Figure 2.10: The Change in Private Surplus under Different VMT Distributions (PV, $2009)



Gasoline Consumption

If a PHEV-20 displaces a similar-sized CV it would reduce gasoline consumption by 45% to 65% over the life of the vehicle (Table 2.9). The reduction in gasoline consumption is particularly sensitive to values assumed for the fuel economy of the CV that is being displaced, the price elasticity of the travel demand, and consumer driving patterns (Figure 2.11-2.13).

Table 2.9: Minimum, Maximum, and Nominal Reduction in Gasoline Consumption Relative to CV (%)

Size of Reduction	HEV	PHEV-20	PHEV-40	PHEV-60
Minimum	26% (1)	45% (1)	59% (1)	69% (1)
Nominal	44%	59%	69%	76%
Maximum	54% (2)	68% (2)	75% (2)	81% (2)

(1) Results when the fuel efficiency of the CV is 35 mpg
(2) Results when the fuel efficiency of the CV is 18 mpg

Figure 2.11: Reduction in Gasoline Consumption Relative to CV under Different CV Fuel Efficiencies (%)

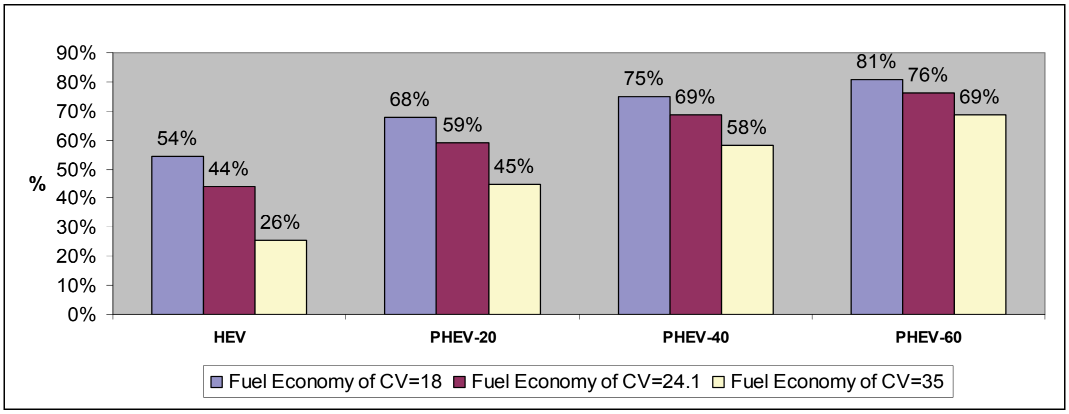


Figure 2.12: Reduction in Gasoline Consumption Relative to CV under Different VMT Demand Price Elasticity (%)

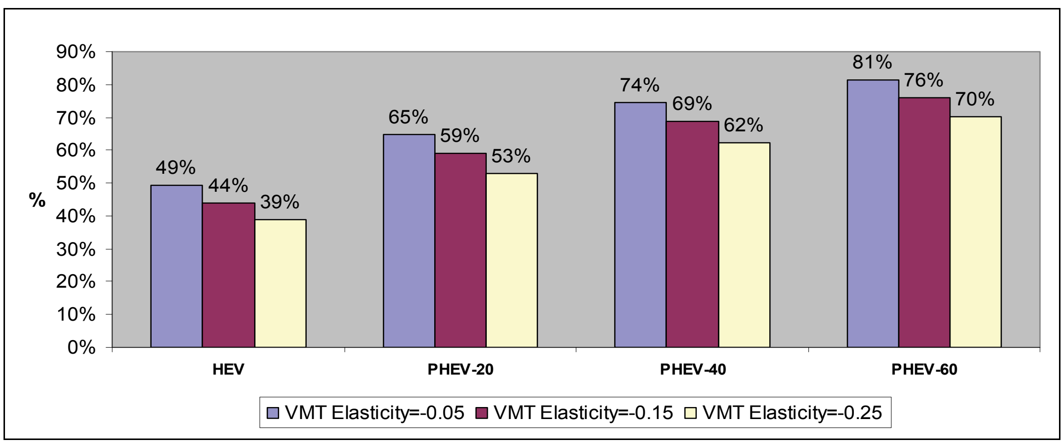
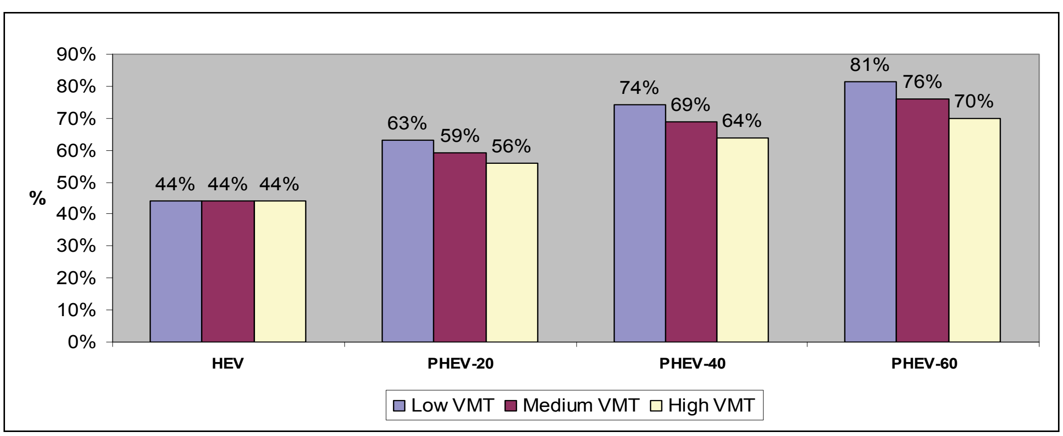


Figure 2.13: Reduction in Gasoline Consumption Relative to CV under Different VMT Distributions (%)



Congestion

Due to improved fuel efficiency, a PHEV-20 is driven substantially more compared to a similar-sized CV (Table 2.10). Changes in the amount of VMT are sensitive to energy prices, driving patterns, the price elasticity of the travel demand, and the fuel efficiency of the CV that is being displaced (see Appendix D for details).

Table 2.10: Minimum, Maximum, Nominal Additional VMT Relative to CV (miles)

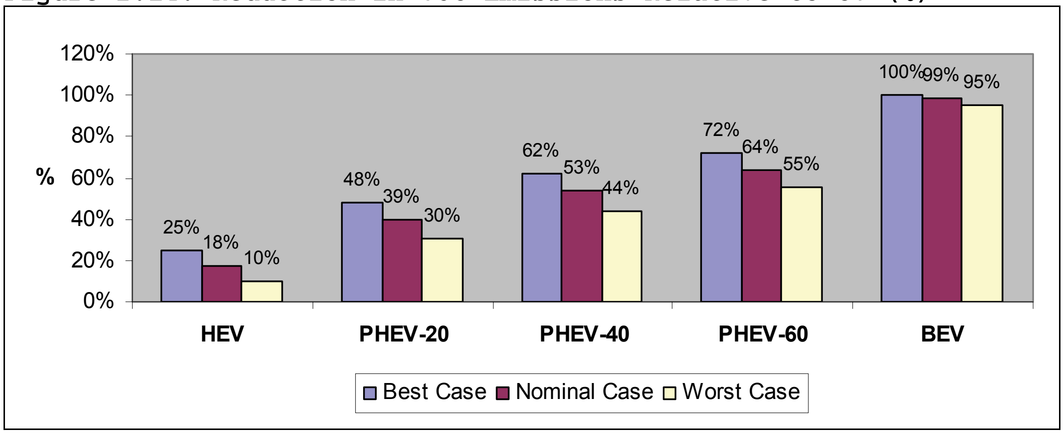
Size of Reduction	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
Minimum	8,160(1)	9,010(1)	9,880(1)	10,360(1)	11,190 (1)
Nominal	24,470	28,210	31,060	32,760	36,120
Maximum	40,790(2)	49,030(2)	54,260(2)	57,490(2)	64,830 (2)

(1) Results when the VMT price elasticity is -0.05
(2) Results when the VMT price elasticity is -0.25

Criteria Pollutants and GHG Emissions

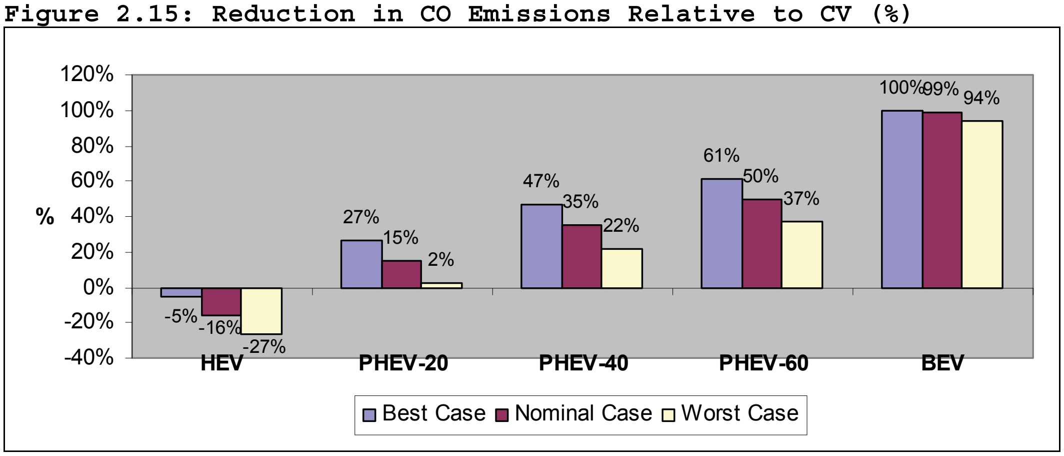
Figures 2.14-2.20 present the maximum, minimum, and nominal estimated change in criteria air pollutants and GHG emissions over the life of an electric vehicle relative to a similar-sized CV.

Figure 2.14: Reduction in VOC Emissions Relative to CV (%)



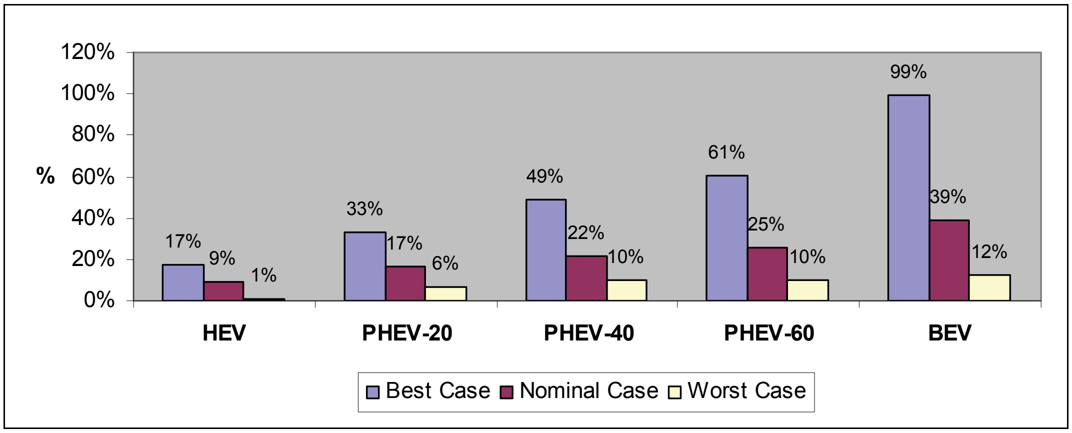
Note: For HEV and PHEV-20, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For HEV, PHEV-20, PHEV-40, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For PHEV-40 and PHEV-60, the best case happens when the VMT elasticity is -0.05, or when VMT follows the low VMT distribution; For PHEV-60, the worst case happens when the VMT elasticity is -0.25, or when VMT follows the high VMT distribution.

Figure 2.15: Reduction in CO Emissions Relative to CV (%)



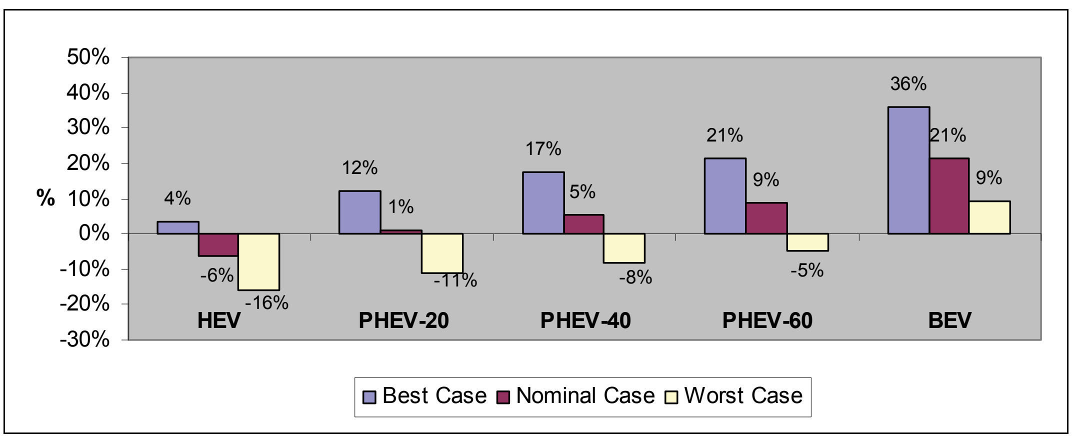
Note: For HEV and PHEV-20, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For HEV, PHEV-20, and PHEV-40, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For PHEV-40 and PHEV-60, the best case happens when the VMT elasticity is -0.05, or when VMT follows the low VMT distribution; For PHEV-60, the worst case (smallest reduction) happens when the VMT elasticity is -0.25, or when VMT follows the high VMT distribution.

Figure 2.16: Reduction in NOx Emissions Relative to CV (%)



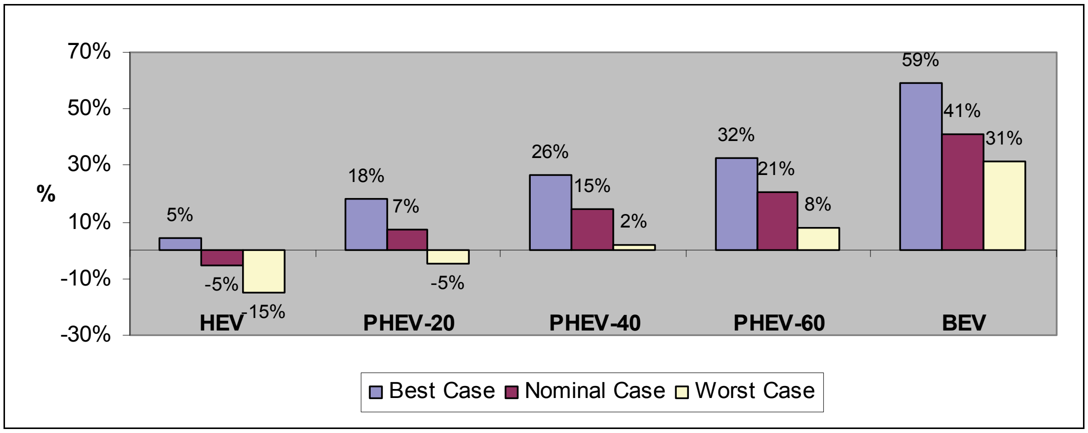
Note: For HEV, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For HEV, PHEV-20, and PHEV-40, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For PHEV-20, PHEV-40, PHEV-60, and BEV the best case happens when electricity is generated by a nuclear power plant; For PHEV-60 and BEV, the worst case happens when electricity is generated by a coal power plant.

Figure 2.17: Reduction in PM10 Emissions Relative to CV (%)



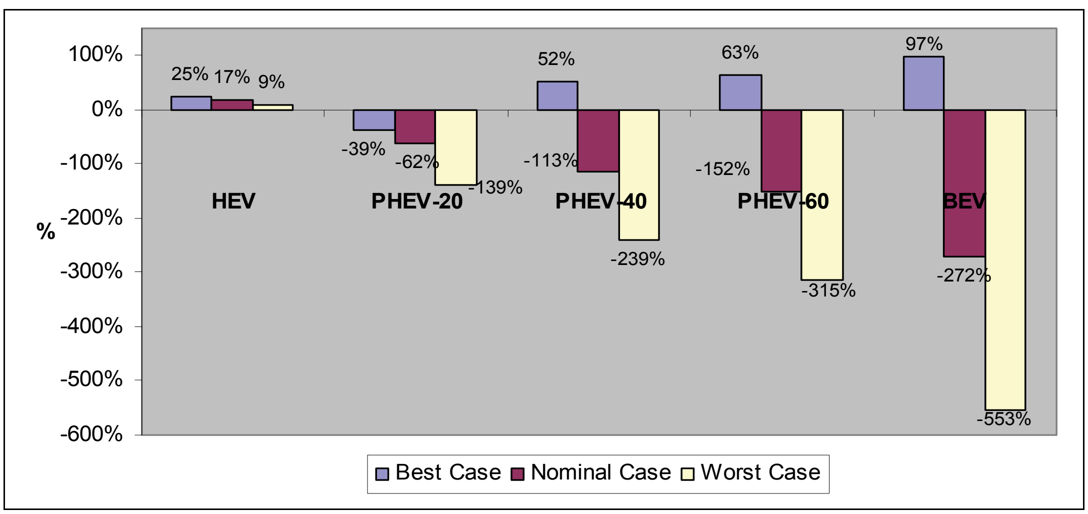
Note: For HEV and PHEVs, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For all, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For BEV the best case happens when the electricity is generated by a nuclear power plant and the worst case happens when the electricity is generated by a coal power plant.

Figure 2.18: Reduction in PM2.5 Emissions Relative to CV (%)



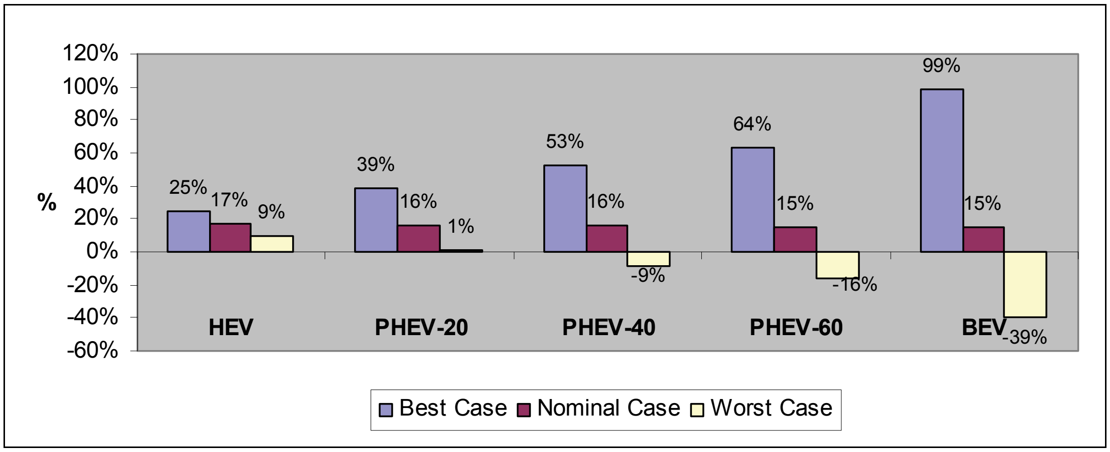
Note: For HEV and PHEVs, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For HEV and PHEVs, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For BEV the best case happens when the electricity is generated by a nuclear power plant and the worst case happens when the electricity is generated by NGCC and coal power plants.

Figure 2.19: Reduction in SOx Emissions Relative to CV (%)



Note: For HEV, the best case (greatest reduction) happens when VMT follows the low VMT distribution; For HEV, the worst case (smallest reduction) happens when VMT follows the high VMT distribution; For PHEVs and BEVs, the best case happens when electricity is generated by nuclear or NGCC power plants and the worst case happens when electricity is generated by a coal power plant.

Figure 2.20: Reduction in GHG Emissions Relative to CV (%)



Note: For HEV, the best case (greatest reduction) happens when the VMT elasticity is -0.05; For HEV, the worst case (smallest reduction) happens when the VMT elasticity is -0.25; For PHEVs and BEVs, the best case happens when electricity is generated by a nuclear power plant and the worst case happens when electricity is generated by a coal power plant.

Changes in emissions when electricity used is generated by different power plant types are shown in Figures 2.21-2.24. As the results suggest the emission reduction gains are larger when the electricity is generated from a nuclear or NGCC power plant compared to a coal power plant. For example, a PHEV-40 that runs on electricity that is generated by a nuclear power plant would reduce GHG emission by 53%. The same vehicle, if operated with electricity that is generated by coal power plant, would actually increase GHG emissions by 9 percent. As shown by these results, having a cleaner electricity generation mix would substantially increase the environmental benefits of electric vehicles. Authorities should take into account the possibility of large-scale demand for electricity in the transportation sector, when investing in new electricity generation facilities.

Figure 2.21: Reduction in Emissions from a PHEV-20 Relative to CV under Different Electricity Generation Conditions (%)

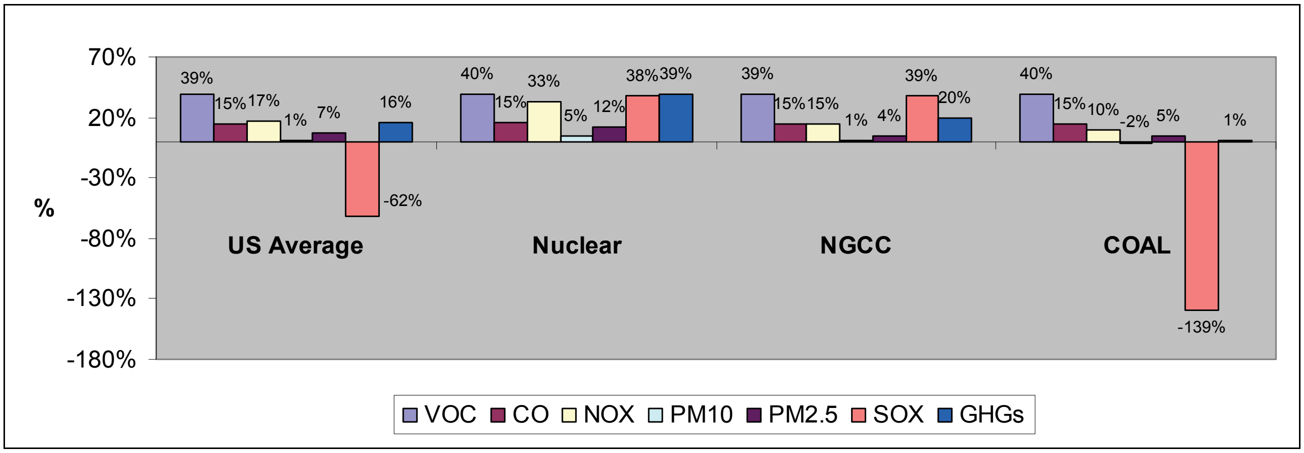


Figure 2.22: Reduction in Emissions from a PHEV-40 Relative to CV under Different Electricity Generation Conditions (%)

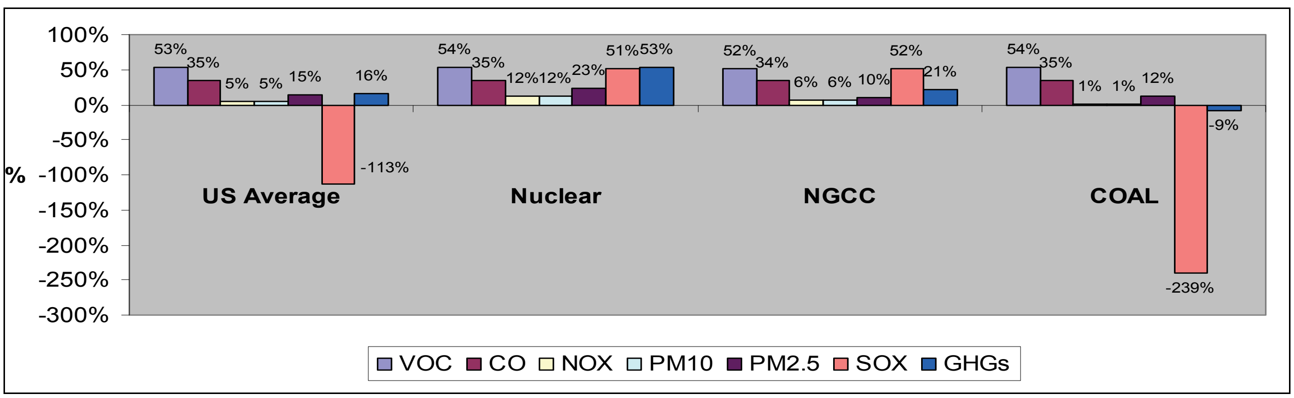


Figure 2.23: Reduction in Emissions from a PHEV-60 Relative to CV under Different Electricity Generation Conditions (%)

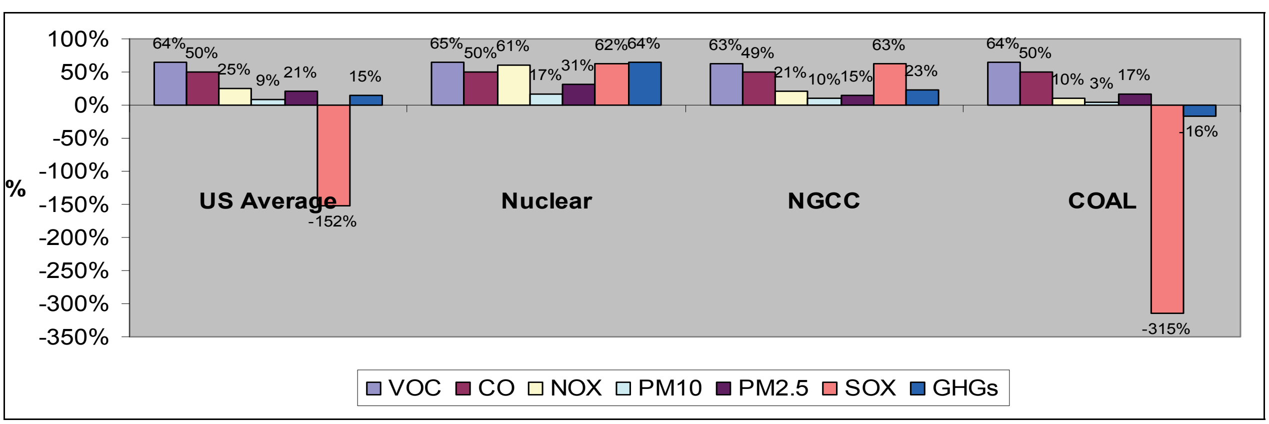
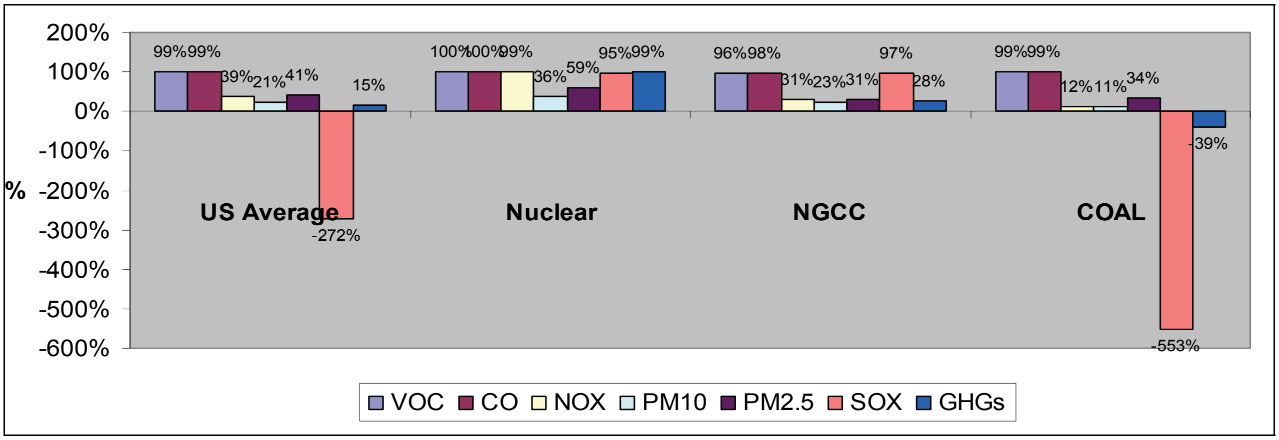


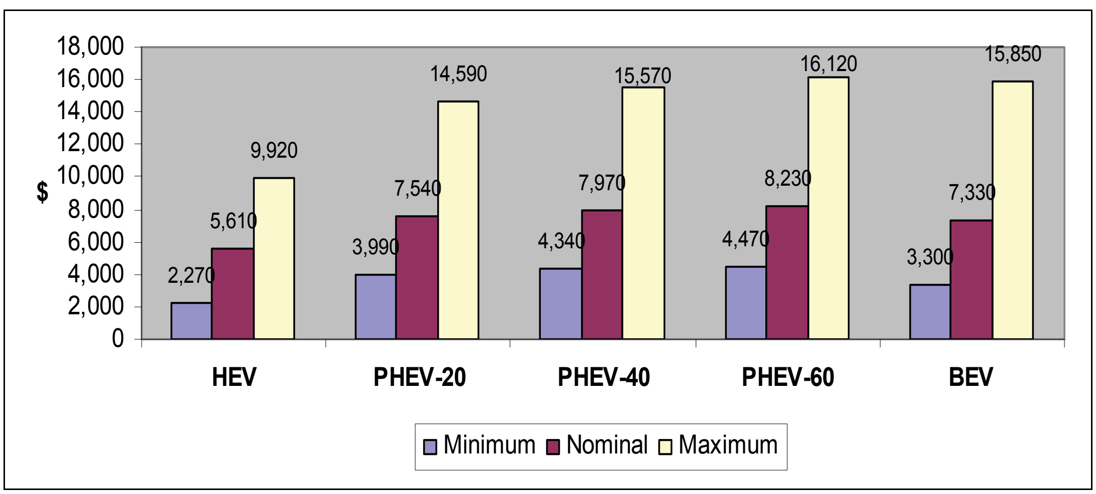
Figure 2.24: Reduction in Emissions from a BEV Relative to CV under Different Electricity Generation Conditions (%)



Monetization of Externalities

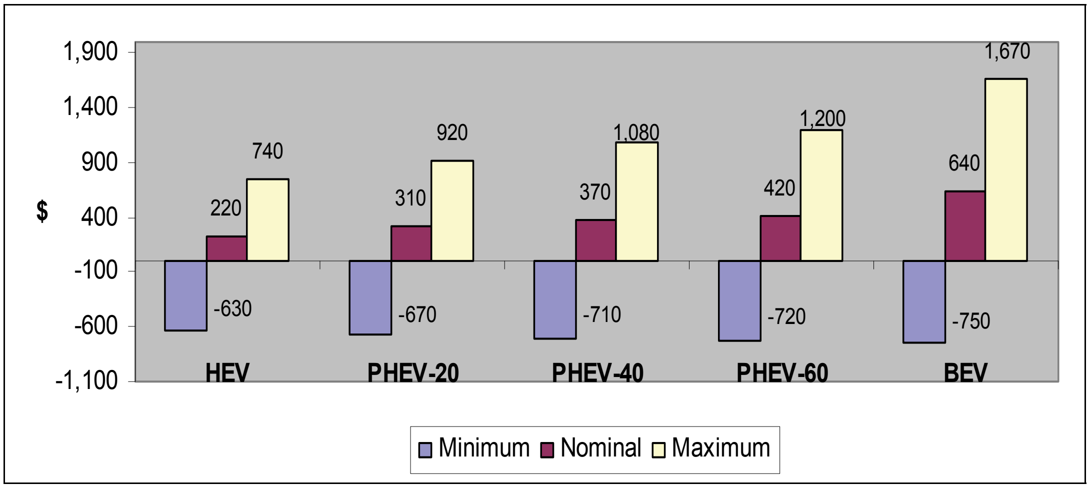
As shown in Figure 2.25, the NPV of the societal benefits from displacing a CV with a similar-sized PHEV-20 could be as little as $3,990 to as much as $14,590 over the life of the vehicle. My nominal case estimate is $7,540. However, the NPV of the external benefits are not likely to exceed $1,700 (Figure 2.26).

Figure 2.25: Minimum, Maximum, and Nominal Societal Benefits Relative to CV (NPV, $2009)



Note: For HEV and PHEV-20 the minimum benefit occurs when CV fuel efficiency=35 mpg; the maximum benefit occurs when gasoline price=4.5 $/gallon; For PHEV-40, PHEV-60, and BEV the minimum benefit occurs when gasoline price=1.5 $/gallon and the maximum benefit occurs when gas price=$4.5/gallon.

Figure 2.26: Minimum, Maximum, and Nominal Net External Benefits Relative to CV (NPV, $2009)



Note: For HEV, PHEV-20, and PHEV-40 the minimum NPV of externalities relative to CV occurs when the congestion damage cost is high. For HEV and PHEV-20, the maximum NPV of externalities occurs when the VMT elasticity is -0.05; For PHEV-40, the maximum NPV of externalities occurs when the benefit from increased energy security is high. For PHEV-60 and BEV, the minimum NPV of externalities occurs when the benefit from increased energy security is low and the maximum occurs when it is high.

POLICY IMPLICATIONS AND RESEARCH CAVEATS

In this section, I discuss the policy implications of the findings of this analysis and the recent policy contexts that affect electric vehicle purchasers and manufacturers. The section concludes with a discussion of the research caveats and future work.

Policies that affect the vehicle purchasers

Subsidies for Electric vehicles

In this section I address two separate questions. First, what is the size of the subsidy required to induce consumers to purchase electric vehicles? Second, would such a tax credit be appropriate from a societal perspective given the external benefits of the subsidy (e.g. decreased GHGs and criteria air pollutants)?

If it is desired to induce consumers to purchase and utilize more electric vehicles, one way to do this would be to offer a subsidy in the form of a tax credit to households that purchase electric vehicles. The size of the tax credit that would help reach that goal equals the difference between the PV of the change in the private surplus and the technology’s cost premium relative to a similar-sized CV.

Since there are no PHEVs for sale at this moment, the short-term cost premiums are unknown. General Motors (GM) is expected to announce the manufacturer’s suggested retail price (MSRP) for its Chevy Volt in 2010. The best estimates place the price close to $40,000 (GM 2009). Chevy Volt is a PHEV-40 and, size-wise, it is closest to the Chevrolet Cobalt sedan. The MSRP for a Chevrolet Cobalt sedan starts at $14,900 (GM 2009), which translates into a cost premium of roughly $25,000 for the Chevy Volt. Such a cost premium is much higher than the gains in private surplus estimated in this paper for a PHEV-40.

I estimate that the PV of the change in private surplus from displacing a CV with a similar-sized PHEV-40 could be as little as $3,670 to as much as $15,500 over the life of the vehicle. My nominal case estimate is $7,600. Thus, the subsidy required to induce most consumers to buy a Chevy Volt would be over $17,000 ($25,000-$7,600=$17,400) according to my analysis.

Ford’s 2010 Fusion hybrid model starts at $27,950 and its conventional non-hybrid model starts at $19,694, which translated into a cost premium of more than $8,000 for the HEV technology. According to my findings, only under a high gasoline price scenario (> $3.5 per gallon) would the fuel cost savings offset such a premium. According to this analysis, under nominal assumptions, a tax credit of at least $2,600 ($8,000-$5,400=$2,600) is needed to induce most consumers to purchase a Ford Fusion hybrid model instead of its non-hybrid counterpart.

Finally, currently there are no “affordable” BEVs on the market. Tesla Roadster, by Tesla Motors, for example, is sold at $100,000. Tesla has plans to produce more affordable BEV models in the next couple of years. The only affordable BEV that is scheduled to be launched in the US market by later 2010 is the Nissan LEAF. Nissan LEAF is an all-electric hatchback that can drive on electricity for up to 100 miles between recharges. The price is not announced yet, but it is expected to be around $30,000 (HybridCars 2010). Size-wise, the Nissan LEAF is closest to the Nissan Versa Hatchback model, with a MSRP that starts at $13,100. This suggests a cost premium of about $17,000 compared to a similar-sized CV, which exceeds the fuel cost savings estimated in this study. Under nominal assumption, the appropriate tax credit to induce most consumers would be more than $10,000 ($17,000-$6,700=$10,300). The tax credit required would be higher for BEVs with larger electric ranges.

Adding the installation costs of recharging facilities at home, with a price tag of roughly $900 per vehicle (Morrow, Karner et al. 2008)[22], the PHEV technology would need governmental support to achieve a significant market share in the near future. NAS (2009) estimates the cost premium to decrease over time. The long-term estimates for additional cost to a purchaser of electric passenger vehicles relative to baseline average gasoline passenger vehicle is shown in Table 2.11.

Table 2.11: Long-term Additional Cost to Purchaser of Electric Passenger Vehicles Relative to Baseline 2035 Average Gasoline Passenger Vehicle

Propulsion System	Additional Retail Price ($2007)
2035 HEV	2,500
2035 PHEV*	5,800
2035 BEV**	14,000

Note: Estimates are adopted from NAS (NAS 2009); * assumes a 30 mile all-electric drive range; ** assume a 200 mile all-electric drive range.

[22] This estimate is for the most economical charging facility that uses a standard 120 VAC, 15 amp or 20 amp branch circuit. This would result in an approximate charging time of 5.5 hours for a PHEV-40. It is possible to upgrade the charging facility to use a 240 VAC, single-phase, 40 amp branch circuit. This would cost about $2,100 and would reduce the charging time of a PHEV-40 to an hour (Marrow, Karner et al., 2008).

These long-term cost premium estimates suggest that the need for subsidies to induce consumers to purchase HEVs and PHEVs would be eliminated in the foreseeable future, but the need for subsidies for BEVs will remain, unless the price of gasoline is high enough (~ $4.5 dollars per gallon) to create fuel cost savings that is large enough to offset the technology premium.

In the American Recovery and Reinvestment Act (ARRA) of 2009 (P.L. 111-5), the federal government has already established tax credits for the purchase of new light-duty PHEVs. The credit is based on the battery capacity of the vehicle and ranges from $2,500 to $7,500 per vehicle (ARRA 2009; Fred Sissine 2009). According to ARRA (2009), once the total sales of vehicle eligible for the credit by each manufacturer reaches 200,000 vehicles, the full amount of the credit will be reduced with respect to a manufacturer's vehicles.

In addition to the federal tax credit, some states offer additional incentives for the purchase of PHEVs. For example, the state of California is providing a rebate of $5,000 for the purchase of BEVs and PHEVs (California Air Resources Board 2010).

Tax credits for HEVs are not discussed in ARRA of 2009. The Energy Policy Act of 2005 (Pub.L. 109-58) granted eligible HEV models a federal income tax credit of up to $3,400. This tax credit is already phased out for some manufacturers, including Toyota and Honda, which have already sold more than 60,000 eligible vehicles. According to the Internal Revenue Services (IRS), as of January 4, 2010, several hybrid models from BMW, Cadillac, Chevrolet, Ford, GMC, Mercury, Mercedes-Benz and Nissan are eligible for a tax credit (IRS 2010).

As the findings of this study suggest, the size of the federal tax credit offered for PHEVs and BEVs in ARRA would not be enough to induce most consumers who make their purchasing decision solely on an economic basis to purchase these vehicles. This is particularly true for lower income vehicle purchasers. This group tends to more heavily discount the future (NHTSA 2006). My analysis suggest that if a consumer discounts the future at a rate of 20% per year, the change in private surplus from purchasing and utilizing a PHEV-40 instead of a CV would be $4,600 instead of $7,600, which is the benefit with a 7% discount rate. This suggests that greater subsidies are required to induce lower income car buyers to purchase electric vehicles. The size of the federal tax credit might be enough to nudge consumers who, besides fuel costs savings, value other non-monetary issues (e.g. environmental protection) as well. And finally, such a tax credit would be a waste of tax payers' money if the car buyer would have bought the electric vehicle regardless of the subsidy.

But, the second question is whether such a tax credit would be justified by the external benefits to society (e.g. decreased GHGs and criteria air pollutants) that result from replacing a CV with a similar-sized electric vehicle?

The findings of this study suggest that the net external benefits are not likely to exceed $1,700, $1,200, and $800 for BEVs, PHEVs, and HEV, respectively. These numbers reflect the NPV of the external benefits gained from changes in GHGs, criteria air pollutants, gasoline consumption, and congestion. Tax credits of similar magnitudes are justifiable.

ARRA(2009) also establishes a tax credit for a vehicle that is converted to become a qualified PHEV. This tax credit is equal to 10% of the cost of conversion and is capped at $4,000 per conversion. These tax credits start on January 1, 2010 and phase out on December 31, 2011. Such a tax credit is not justified by the findings of this study.

The current market price of converting a Toyota Prius to a Toyota PHEV is about $10,000. The private surplus gained from driving a PHEV-40 instead of a HEV is about $2,200 ($7,600-$5,390=$2,210). So, from a vehicle owner's perspective, such a conversion would not make economical sense, even if one factors in the 10% tax credit. Clearly, consumers who are willing to pay for such a conversion would do so for non-economical reasons and would have done so without the tax credit. Such a tax credit would not be effective in inducing many consumers to convert their HEVs into PHEVs. Even if it were, the resulting external benefits to society from such a conversion would have been at most $340 ($1,080-$740), which is much smaller than the cost.

Note that this analysis does not consider market failure issues that might be present on the manufacturing side: the prevalence of innovation market failure and underinvestment in new technologies. By creating demand for new technologies, tax credits could promote innovation in the auto industry. If this benefit could be quantified, larger subsidies might have been justified.

Also, as in all cost-benefit analysis studies, the estimated NPV of externalities are as accurate as the monetary estimates of the social damage cost of the externalities taken from the literature (Boardman, Greenberg et al. 2006). For example, estimates of the damage costs of CO2 emissions range from negative and near zero values to over 200 dollars per ton of CO2-equivalent (Tol 2005). However, despite the controversy and uncertainty, there seems to be some consensus on narrower ranges of the societal damage costs of externalities. In this study, I try to use such ranges.

Regardless of the size of the subsidy, there are ways to make them more efficient. As the findings in the sensitivity analysis suggest, the NPV of the societal benefits is particularly sensitive to the fuel efficiency of the CV that is being displaced, gasoline and electricity prices, consumers driving behavior, size of the discount rates and rebound effect, electricity generation source, and damage costs used for the GHG, energy security and congestion. Thus, similar to Skerlos et al (2009), the findings of this analysis suggest that the efficiency of the subsidies can be improved if instead of a uniform subsidy scheme, larger subsidies are offered in regions with larger external benefits and smaller ones are offered in regions with smaller external benefits.

Raising gasoline prices relative to the price of electricity

Increasing the gasoline tax would increase the fuel cost savings and incentivize consumers to switch to more fuel-efficient vehicles including electric vehicles. Elevated fuel taxes have been a key factor in shaping the favorable preference of European car buyers towards more fuel-efficient vehicles. However, an increase in the gasoline tax in the US is unlikely, given that legislative bodies have been reluctant to raise per gallon fuel taxes. For example, the federal per gallon tax on gasoline (at 18.4 cents per gallon) has not been increased since 1993 and has not been indexed to inflation.

As shown in Table 2.12, if the price of gasoline would have been $8, similar to that in Europe, the private surplus gains from switching to electric vehicles would have been large enough to offset their cost premiums, suggesting that subsidies would not be necessary to promote adoption for most consumers.

Table 2.12: The Change in Private Surplus when Price of Gasoline is $8 per Gallon (PV, $2009)

HEV	PHEV-20	PHEV-40	PHEV-60	BEV
17,250	27,210	29,340	30,550	31,650

Interestingly, despite the large private surplus, some European countries are offering tax credits for electric-vehicle technologies. For example, France is offering a 5000-euro subsidy to purchasers of electric-vehicles (Deutsche Welle 2009; Nemry, Leduc et al. 2009).

Reducing electricity prices for use in transportation would be another way to increase private surplus. Utilities might want to offer discounts for use of electricity in the transportation sector. Of course, the operational cost of implementing such differential pricing mechanisms would be non-trivial (e.g. special smart-metering systems, systems to prevent people stealing cheap electricity to use in other applications).

<u>Introducing VMT taxes</u>

Under a VMT fee, drivers would be charged on a per-mile basis. This fee could be designed to change with factors such as the time and location that driving occurs, the congestion level, and the weight and fuel type of the vehicles. Since VMT taxes will be based on miles driven rather than the amount of fuel consumed, they will discourage the additional driving that would result from improved fuel efficiency, and thus, could increase the net external benefits that would result from replacing a CV with an electric vehicle. However, this would also reduce the private benefits. Table 2.13 presents the change in private surplus and net societal benefits under a hypothetical scenario when the gasoline tax is replaced by a VMT fee equal to 1.5 cents per mile.

Table 2.13: The Change in Private Surplus and Net External Benefits under a VMT Fee (NPV, $2009)

Scenario	Benefit /Cost Type	HEV	PHEV-20	PHEV-40	PHEV-60	BEV
Fuel Tax=47 cents per mile VMT Fee=0 cents per mile	Change in Private Surplus	5,390	7,230	7,600	7,810	6,690
	Net External Benefits	220	310	370	420	640
Fuel Tax=0 cents per mile VMT Fee=1.5 cents per mile	Change in Private Surplus	5,160	5,730	5,850	5,910	4,510
	Net External Benefits	210	560	670	760	1,030

<u>Other Policies to promote the adoption of Electric Vehicles</u>

Another policy that could promote the use of more fuel-efficient vehicles, including EVs, is introducing “feebates”, which means charging less fuel-efficient vehicles a fine and awarding more fuel-efficient ones a rebate. Also, there are non-economic incentives such as providing access to High Occupancy Vehicle (HOV) lanes regardless of the number of occupants in the vehicle that would provide additional incentives to consumers to purchase electric vehicles. For example, California has such an incentive in place for a limited number of electric and hybrid electric vehicles until January 1, 2011(California DMV 2004).

Policies that affect vehicle manufactures

<u>Investing in battery research and development to reduce cost and increase lifespan</u>

The main electric vehicle cost component is its battery pack. One way to reduce the cost premium is to invest in battery technology research and development. According to NAS(2009) currently the lithium-ion batteries that have the cycle life desired for automotive applications cost between $500/kWh and $1000/kWh. However, the economical unit cost of stored energy that is set by the US Advanced Battery consortium is $35/kWh and $100/kWh for PHEVs and BEVs, respectively (NAS 2009).

As part of the Energy Independence and Security Act of 2007 (EISA 2007), the Department of Energy provides both grants and direct loans to support the development of advanced technology vehicles, including PHEVs and BEVs, and related components. This program is known as the Advanced Technology Vehicles Manufacturing Loan Program (ATVM). For example, a $528.7 million conditional loan was granted to Fisker Automotive for the development of two lines of PHEVs: the Fisker Karma and Fisker's Project Nina. The Fisker Karma is the first PHEV manufactured by Fisker Automotive and has a price tag of $87,900 (Fisker Automotive 2010). Project Nina is a more affordable PHEV and is expected to be manufactured in volumes up to 100,000 every year starting in 2012 (DOE 2009).

Another example is a $1.4 billion loan to Nissan North America, Inc. to produce electric vehicles and advanced battery packs at its manufacturing complex in Smyrna, Tennessee. Nissan plans to manufacture about 150,000 Nissan LEAFs annually and 200,000 battery packs (DOE 2010).

Also, Tesla Motors has received a $465 million loan to manufacture the Tesla Model S electric vehicle, battery packs and electric drive trains to be used by Tesla as well as other automakers (DOE 2009). Tesla Model S is a sedan and is expected to cost about $50,000, which is more affordable than the already available Tesla Roadster with a price tag of $100,000. Tesla Motors is planning to start the production of Model S in 2011 and increase production up to 20,000 vehicles per year by the end of 2013 (DOE 2009).

<u>Fuel Economy and GHG Emissions Proposals</u>

The US Energy Independence and Security Act of 2007 ((EISA 2007); P.L.110-140) requires that CAFE standards be set for light-duty vehicles for model years 2011 through 2020. In May 2009, President Obama proposed that these requirements, specified by Subtitle A of EISA 2007 (P.L.110-140), be accelerated (The White House 2009). The new provision aims to ensure that, by 2016, the industry-wide CAFE for all new passenger cars and light trucks combined will be at least 35.5 mpg.

The National Highway Traffic Safety Administration (NHTSA) and EPA have announced coordinated standards for the fuel economy and GHG emissions for Model Years 2012-2016. NHTSA has proposed CAFE standard under the Energy Policy and Conversation Act (EPCA)[23], as amended by the Energy Independence and Security Act (EISA 2007) and EPA has proposed GHG emission standards under the Clean Air Act (CAA).

To achieve significant reductions in GHG emissions and improvements in fuel economy from the light-duty vehicle element of the transportation sector, both agencies provide incentives for commercially available technologies that can be incorporated at reasonable costs, including EVs and PHEVs (Federal Register 2009)

Under the proposed rule, eligible advanced vehicle technologies such as BEVs and PHEVs would get extra compliance credits, meaning that they would count as more than one vehicle when annual fleet fuel efficiency averages are calculated (Federal Register 2009). These additional credit opportunities, along with increased regulatory certainty, would induce manufacturers to innovate and boost the development of electric vehilces.

<u>ZEV Mandate</u>

The Zero-Emission Vehicle (ZEV) mandate in California, set by the California Air Resources Board (CARB), requires all vehicle manufacturers selling in the state to offer for sale a minimum number of zero-emission vehicle and near zero-emission vehicles. Vehicle technologies are categorized as ZEVs(e.g. BEVs), enhanced advanced

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[23] EPCA fuel economy requirements assigned to the Secretary of Transportation. 49 CFR 1.50,501.2(a)(8)

technology partial ZEVs or enhanced AT PZEVs (e.g. PHEVs), and AT PZEVs and PZEVs (e.g. HEVs).

Currently, CARB is in the process of revising the ZEV mandate. In the preliminary assessment of the need for revisions (CARB 2009), CARB’s staff recommended that PZEVs be dropped from the regulation by 2014 and AT PZEVs by 2017, because these technologies have already been successfully commercialized (HEVs fall into these categories). They recommend focusing on ZEVs and enhanced AT PZEVs, instead (PHEVs and BEVs fall into these categories). PHEVs are considered enhanced AT PZEVs, and not ZEVs, because their true GHG reduction benefit depends on the amount of the gasoline that is being displaced by electricity and on the type of electricity used. PHEVs will likely continue to be part of the future ZEV regulation, but receive less credit than a ZEV (CARB 2009).

Regulations such as the Zero Emission Vehicle (ZEV) program in California would provide incentives to vehicle manufacturers to invest in clean vehicle technologies and would help pre-commercialize these technologies.

Caveats and Future Research

There are several potential sources of bias in my estimates. First, in estimating the private benefits, I only considered the fuel cost savings and mobility benefits. Various non-marketable benefits such as the utility gained from protecting the environment or promoting oil independence are not estimated here. Once PHEVs and BEVs are introduced into the market, more research can be done to understand the decision making process of consumers who purchase and utilize electric vehicles and to quantitatively or qualitatively address other types of benefits.

Also, I assumed that the maintenance and insurance costs of a new electric vehicle are similar to those of a similar-sized CV. However, these costs are likely to be substantial for the new technologies. There is little data available at this time to study the validity of this assumption or to justify assuming otherwise. Also, it is assumed that electric vehicles have the same survival rates and performance as CVs. Future work should look at potential performance advantages and disadvantages of electric vehicles compared to CVs.

Also, there is a concern that the quietness of electric vehicles may be unsafe for pedestrians. The validity of this statement should be studied and potential manufacturing options to address this concern should be explored.

Consumers’ vehicle charging patterns is another issue that lies outside of the scope of this study. I assume that the vehicle is fully recharged each day. However, the estimated benefits would decline if the vehicle owner chooses to charge the vehicle less frequently. Obviously, the charging patterns depend on access to charging facilities. More studies are needed to explore existing limitations to accessing electrical outlets at home, at work, and in public charging facilities and the equity issues that might arise from that, as well as the infrastructure investment costs associated with providing access to public charging facilities. The latter is particularly important for the success of BEVs.

Future research should study the effect of a large-scale vehicle fleet electrification on the national and state-level electricity infrastructure. Kintner-Meyer et al(2007) assessed the impact of plug-in hybrid vehicles on the US electric power infrastructure and found that with current generation capacity over 70 percent of the energy consumed in the US light-duty vehicle fleet could be replaced by electricity. According to their study, this number would be significantly smaller if vehicles were limited to recharging over night. Even though national generation capacity might be sufficient to support large-scale adoption of electric vehicles, the transmission and distribution infrastructure might face substantial adaptation costs associated with large-scale electric vehicle adaptation. More studies are needed to understand the regional impacts, especially impact on the electricity transmission and distribution infrastructure in dense neighborhoods.

On the other hand, more research is needed to understand the potential benefit of electric vehicles to enhance the electricity generation and distribution system and generate revenue for the owner by storing electricity when demand is low and using/or selling it back when demand is high. Obviously, to realize this benefit technical and social impediments need to be addressed, and vehicle-to-grid infrastructure needs to be developed (Sovacool and Hirsh 2009). Other issues that are beyond the scope of this paper, but should be addressed in future work, are the resource availability and environmental protection implications of using lithium for EV production.

CONCLUSIONS

The transportation sector generates one-fourth of US GHG emissions and accounts for two-thirds of its gasoline consumption. The electrification of this sector, with the aim of reducing GHG emissions and dependence on oil, has been a central concept in many recent policy debates. In this paper, the benefits and impacts of driving three electric vehicle technologies (HEVs, PHEVs, and BEVs) instead of a similar-sized CV have been studied. A spreadsheet simulation model has been developed to explore two different perspectives on the benefits and impacts: private and societal.

The private perspective accounts for the fuel cost savings and the change in private surplus of the vehicle purchaser. I found that the private benefits are significant, but are not large enough to offset the technology cost premiums, at least in the short term. Specifically, I found that under the nominal assumptions the present values of the fuel cost savings from replacing a CV with a similar-sized HEV, PHEV-20, PHEV-40, PHEV-60, and BEVs are $4,370, $6,140, $6,460, $6,640 and $5,460, respectively, and the present values of the private surplus changes are $5,390, $7,230, $7,600, $7,810, and $6,690, respectively. These benefits are smaller than the expected short-term technology cost premiums. However, these are lower-bound estimates of the amount of money a vehicle purchaser is willing to pay extra to own an electric vehicle instead of a CV, given that non-economic benefits such as utility gained from protecting the environment are not quantified. Furthermore, I found that these estimates are sensitive to energy prices, vehicle owners' driving patterns, the way in which the future is discounted, and the fuel efficiency of the CV that is being displaced.

The societal perspective accounts for changes in GHG emissions and criteria air pollutants, gasoline consumption and the driver's contribution to congestion in addition to private surplus. These are presented in both physical as well as monetary terms. I found that PHEVs and BEVs would emit less GHGs and criteria air pollutants relative to CVs, except when the electricity used is generated by coal power plants. Also, I found that changes in GHG emissions are negligible when a PHEV or a BEV replaces a similar-sized HEV. In general, larger reductions could be obtained if the electricity was generated by lower-emission technologies. Also, the size of the reductions found in this study is smaller than those suggested in previous studies, after controlling for the rebound effect. I also found that EVs would substantially reduced gasoline consumption: a HEV, PHEV-20, PHEV-40, and PHEV-60 would respectively consume 44%, 59%, 69% and 76% less gasoline than a similar-sized CV. Also, due to improved fuel efficiency, EVs will be driven substantially more over their life compared to a similar-sized CV. These estimates are particularly sensitive to values assumed for the fuel economy of the CV being displaced, the price elasticity of travel demand, and the consumers' driving patterns.

The findings of this paper can inform several policy deliberations that aim at incentivizing the purchase and production of electric vehicles. For example, according to the findings of this study, the current subsidies in ARRA (2009) are not enough to induce most consumers to purchase and utilize EVs, but larger subsidies are also not justified by the external societal benefits. Also, the efficiency of subsidy programs can be enhanced if they are tailor-made for regions as opposed to being uniform across regions.

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THIRD ESSAY: HYBRID-ELECTRIC VEHICLES AND IMPLICATIONS FOR TRANSPORTATION FINANCE[24]

INTRODUCTION

With the aim of increasing fuel economy and reducing greenhouse gas (GHG) emissions, in May 2009, President Obama announced a new national policy that requires an average fuel economy standard of 35.5 mpg for new light-duty vehicles sold in 2016 (The White House 2009). This standard will be more stringent than the Corporate Average Fuel Economy (CAFE) law passed by Congress as part of the U.S. Energy and Security Act of 2007 that required an average fuel economy of 35 mpg in 2020 (EISA 2007).

With the same environmental and energy independence goals in mind, as part of the Energy Independence and Security Act of 2007 (EISA 2007), the Department of Energy also provides both grants and direct loans to support the development of advanced technology vehicles, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and related components.

Although improved fuel efficiency and vehicle electrification would result in numerous benefits, including reductions in greenhouse gas emissions and gasoline consumption, a complicating issue is that they would also reduce fuel tax revenues needed to fund transportation projects.

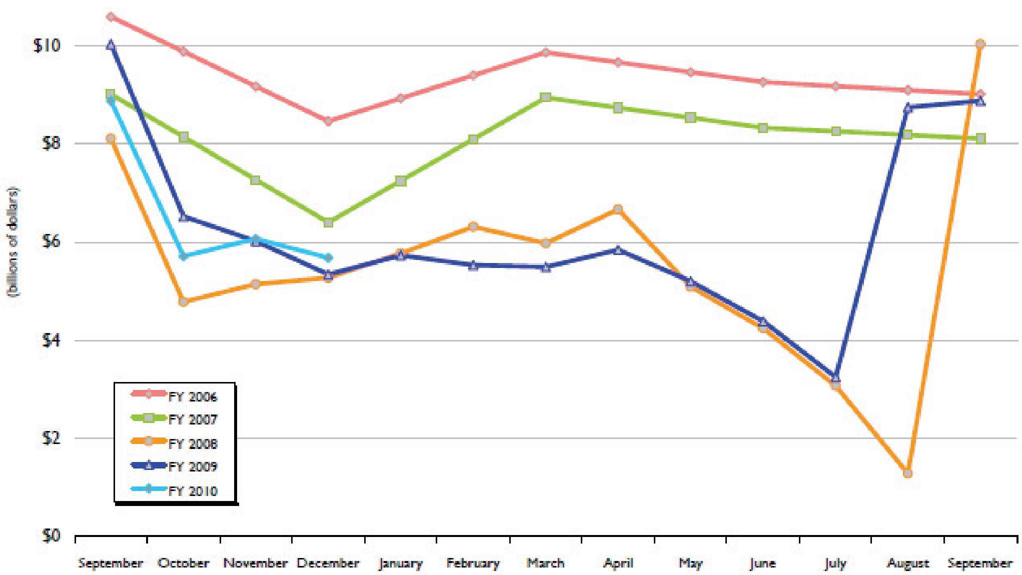
Since the creation of the Federal Highway Trust Fund when the Interstate Highway Program was adopted in 1956, both federal and state transportation projects have been financed primarily through fuel taxes collected at the state and federal levels. Gasoline and diesel taxes are considered to be "road user fees" and states and federal governments depend upon revenues from these taxes to fund planning, construction, maintenance, and operations of state highways and public transit systems. Funds collected through such taxes are usually deposited into "trust funds" whose expenditures are designated for transportation

[24] Co-authored with Martin Wachs

system construction, operation, and maintenance and these funds are usually not mingled with general revenues of governments collected from other taxes and used to cover other expenses.

Transportation finance in many states and at the federal level is already in crisis and the cash balances in these trust funds, as shown in Figure 3.1, are plummeting (Federal Highway Administration 2010). This is attributable to several factors including improvements in average vehicle fleet fuel efficiency, constant fuel taxes, and high transportation infrastructure costs. The current revenues are insufficient to maintain and upgrade the nation’s transportation infrastructure (TRB 2006; NSTIF 2009). However, legislative bodies have been reluctant to raise per gallon fuel taxes while petroleum costs have been rising rapidly. The federal per gallon tax on gasoline (at 18.4 cents per gallon), for example, has not been increased since the early 1990s and has not been indexed to inflation. In recent months Congress has twice appropriated general fund revenue to prop up a failing federal trust fund as user fee revenues have steadily declined. While there is a great deal of variation among the fifty states, in general revenue from motor fuel taxes is falling behind the rate of inflation and estimates of needed spending for highways and transit in many states and they are gradually reducing those expenditures or relying increasingly upon general fund sources rather than user fees.

Figure 3.1: The Highway Trust Fund Balance



Source: (Federal Highway Administration 2010)
The ending balance for FY 2008 includes $8.017 billion transferred from the General Fund in September 2008 pursuant to Public Law 110-318. Ending balance for FY 2009 includes $7 billion transferred from the General Fund in August pursuant to Public Law 111-46

In this study, first the magnitude of the combined federal and state forgone fuel tax revenues when a plug-in hybrid electric vehicle (PHEV) or a gasoline-electric hybrid vehicle (HEV) displaces a similar-sized conventional gasoline-powered vehicle (CV) is estimated. Next, the impacts on fuel tax revenues under different vehicle electrification scenarios are explored. Finally, a policy alternative to recoup the financial losses while not slowing vehicle electrification is discussed.

APPROACH

Model

The forgone fuel tax revenue from displacing a CV with a similar-sized HEV or PHEV is calculated as the difference between their corresponding aggregate gasoline tax revenues. The aggregate gasoline tax revenue over the life of a vehicle is calculated as shown in Equation 3.1:

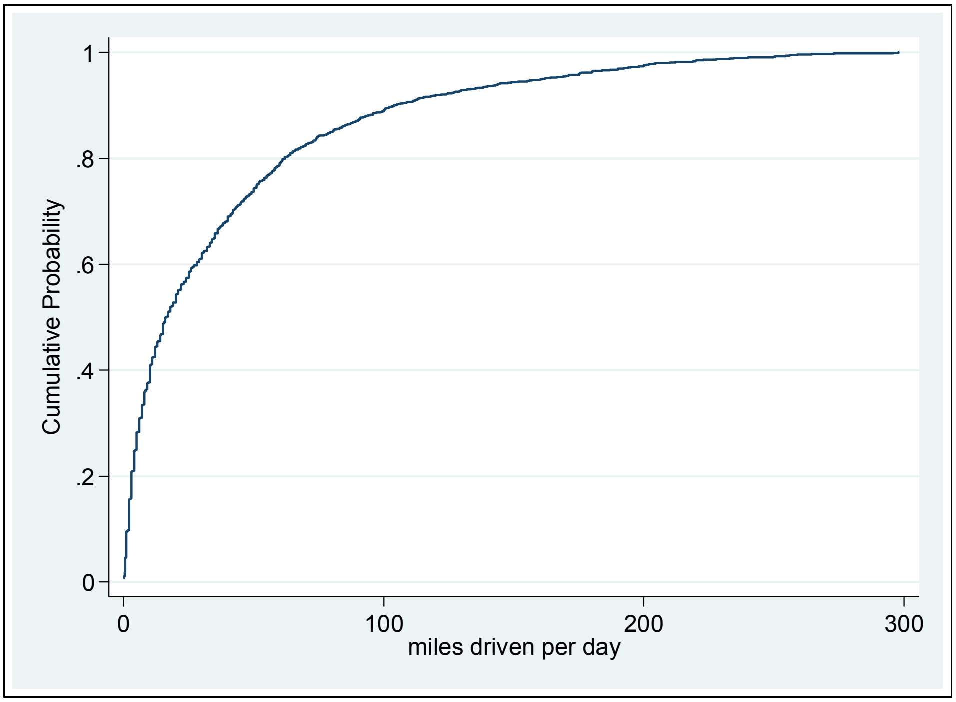
$$r_k = \phi * s_t * \alpha_t * \sum_{t=1}^{30} \frac{g_{t,k}}{(1+\delta)^{t-1}} \qquad (3.1)$$

where the gasoline tax revenue is denoted r_k, $k \in \{CV, HEV, PHEV\}$ is an index indicating vehicle type, ϕ represents the average gasoline tax per gallon, δ represents the discount rate, and t=0,1,… is an index indicating time or vehicle age.

The variable s_t denotes the probability that a vehicle is still operational in year t. Vehicles may stop being used because of accidents or mechanical failures. In principle s_t could vary across vehicle types although little data exist at this point to justify using different survival rates across different vehicle types. The maximum lifespan of a vehicle is assumed to be 30 years. The weighted average lifespan of the vehicle, considering the survival probability, is about 16 years. To account for the fact that older vehicles tend to drive fewer miles per year than newer ones, a miles reduction factor α_t is used to represent the percentage of days a vehicle of age t is driven each year.

The variable $g_{t,k}$ represents the amount of gasoline consumed by each vehicle class k in year t. To estimate $g_{t,k}$ the first step is to identify the vehicle's cumulative distribution function (CDF) of daily VMT. This distribution is constructed for gasoline-powered conventional passenger cars using data from the National Household Travel Survey (NHTS)(DOT 2001). Figure 3.2 presents the base-case VMT distribution calculated from data for all households included in the NHTS. This distribution is adjusted for HEVs and PHEVs to account for the fact that as the cost of driving per mile changes, so will the amount of driving that households will tend to engage in. For details regarding these adjustments refer to Appendix E.

Figure 3.2: CDF of Daily VMT for Primary Gasoline-Powered Vehicles



For analytical purposes, the empirical VMT CDF is approximated with a discrete distribution that consists of 20 blocks, each representing 5 percent of the distribution. The VMT value associated with the ith block (or quantile) is denoted $q_{t,k,i}$ where i=1,2,...,20 is an index indicating a quantile of the daily VMT distribution[25]. The amount of gasoline consumed by each vehicle class k in year t ($g_{t,k}$) is calculated as equation 3.2.

$$g_{t,k} = \begin{cases} \dfrac{\sum_{i=1}^{20} q_{t,k,i}}{\mu_k} & \text{if } k = \{CV, HEV\} \\ 0 & \text{if } k = \{PHEV\} \text{ and } q_{t,k,i} \le X \\ \dfrac{\sum_{i=1}^{20} (q_{t,k,i} - X)}{\mu_k} & \text{if } k = \{PHEV\} \text{ and } q_{t,k,i} \ge X \end{cases} \tag{3.2}$$

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[25] For example, $q_{5,CV,4}$ represents the 4^{th} (or 20%)-quantile on the daily VMT CDF for a CV in year 5.

where μ_k is the gasoline fuel efficiency in mpg of vehicle class k and X is the distance at which PHEVs can be driven on electricity before they must switch to gasoline.

Parameterization of the Model

The average gasoline tax (ϕ) among US states is 47 cents per gallon, including a federal tax of 18.4 cents per gallon (American Petroleum Institute 2009).

After merging the NHTS Daily Trip and Vehicle data files (DOT 2001), VMT distributions are constructed for passenger cars that are driven less than 10,000 miles per year (low-mileage vehicles), between 10,000 and 17,000 miles per year (medium-mileage vehicles), and more than 17,000 miles a year (high-mileage vehicles). The forgone tax revenue is estimated for each of the three CDFs. For details on the VMT CDFs refer to Appendix C.

Improving the fuel efficiency of a vehicle reduces the cost of driving it a mile. The lower cost in turn results in additional driving, which causes more fuel consumption. This phenomenon is called the rebound effect (Greene, Kahn et al. 1999; A. Greening, Greene et al. 2000; Portney, Parry et al. 2002; Small and Van Dender 2007). Using the price elasticity of vehicle miles traveled, the additional miles driven when the driver operates a HEV or a PHEV instead of a CV is estimated. Several studies have estimated the price elasticity of VMT (Mayo and Mathis 1988; Gately 1990; Greene, Kahn et al. 1999). Most estimates fall between -0.10 to -0.25, In this study, the nominal price elasticity of travel demand is considered to be -0.15, but low and high values (-0.05 and -0.25) are also considered in the sensitivity analysis.

Vehicle survival rates (s_t), or the probability that a vehicle is still operational in year t, are taken from Davis et al (2009). It is also important to take into account the fact that a vehicle's utilization decreases as it ages. A factor (α_t) is calculated from data on average annual miles per household vehicle by vehicle age in Davis et al (2009). See Appendix A for the actual values of s_t and α_t used in this study.

As suggested in OMB Circular A-4 (2003), the prevailing real discount rate (δ) considered in this study was 7 percent. Also, three all-electric ranges are considered for a PHEV: 20, 40, and 60 miles. Also, since frequent deep cycle discharges— beyond 80 percent of the electricity stored in a fully-charged battery— will reduce battery longevity (Kromer and Heywood 2007), in this study it is assumed that a PHEV consumes 80 percent of the energy stored in a fully-charged battery before using the gasoline-powered internal combustion engine. Thus, the distance at which a PHEV-20, PHEV-40, and PHEV-60 can be driven on electricity before the need to switch to gasoline, is assumed to be 16, 32, and 48 miles, respectively.

According to EPA (2008), the average combined fuel economy of a gasoline-powered model year 2008 conventional passenger car (μ_k) is 24.1 mpg[26], which is the value assumed for the CV fuel economy in the nominal case. The forgone tax revenue is also estimated when the fuel efficiency of the CV that is being displaced is 18 mpg and when it is 35 mpg. A fuel economy of 50 mpg is assumed for HEVs, which is similar to that of a 2010 model Toyota Prius reported on www.fueleconomy.com. Following Kammen et al (2008), Lemoine et al (2008), and EPRI and NRDC (2007), it is assumed that the fuel efficiency of a PHEV is 4 miles/kWh when it is operating in a charge-depleting mode.

The retail gasoline price, including federal and state gasoline taxes, has increased from an average of $1.10 per gallon in the nineties to over $4.00 per gallon in 2008. The average gasoline price in 2000 was over $2.00 per gallon (EIA 2009). Thus, a gasoline price of $2.50 per gallon was assumed for comparison. This value is also consistent with the average forecasted gasoline price in the 2009 Annual Energy Outlook (EIA 2009).

According to 2009 Annual Energy Outlook, the average residential price of electricity in the US is expected to be 10 cents per kWh in

[26] Value represents a harmonic average of 55 percent city fuel economy and 45 percent highway fuel economy.

2010 (EIA 2009); which is the value assumed for the national residential average price in this study.

RESULTS

Forgone Fuel Tax Revenue Estimates per Vehicle Type

Tables 3.1 present the estimated forgone fuel tax revenues over the life of different vehicle types relative to that of a similar-sized CV, with a fuel efficiency of 24.1, 18, and 35 mpg, respectively.

Table 3.1: Forgone Tax Revenues over the Life of Vehicle Relative to a CV (PV, $ 2009)

a: CV fuel economy is 24.1 mpg

VMT distribution	Low			Medium			High		
VMT Elasticity	-0.05	-0.15	-0.25	-0.05	-0.15	-0.25	-0.05	-0.15	*-0.25*
HEV	710	630	560	920	820	720	1,170	1,050	920
PHEV-20	990	910	820	1,210	1,100	990	1,460	1,330	1,180
PHEV-40	1,140	1,070	980	1,390	1,280	1,160	1,650	1,510	1,360
PHEV-60	1,240	1,170	1,090	1,520	1,420	1,310	1,790	1,660	1,510

b: CV fuel economy is 18 mpg

VMT distribution	Low			Medium			High		
VMT Elasticity	-0.05	-0.15	-0.25	-0.05	-0.15	-0.25	-0.05	-0.15	-0.25
HEV	1,200	1,120	1,050	1,550	1,450	1,360	1,970	1,850	1,730
PHEV-20	1,480	1,400	1,310	1,840	1,740	1,620	2,270	2,130	1,990
PHEV-40	1,630	1,550	1,470	2,020	1,910	1,800	2,450	2,320	2,170
PHEV-60	1,720	1,660	1,580	2,150	2,050	1,940	2,600	2,470	2,310

c: CV fuel economy is 35 mpg

VMT distribution	Low			Medium			High		
VMT Elasticity	-0.05	-0.15	-0.25	-0.05	-0.15	-0.25	-0.05	-0.15	-0.25
HEV	260	190	110	340	240	140	430	310	180
PHEV-20	540	460	370	630	520	410	720	590	440
PHEV-40	690	620	530	810	700	580	910	770	620
PHEV-60	790	720	650	930	840	730	1050	920	770

Note: assumes price of gasoline= 2.5 $/gallon (includes a tax of 47 cents per gallon); price of electricity=0.1 $/kWh; discount rate=0.07; fuel economy of a HEV is 50 mpg; fuel economy of PHEV is identical to that of HEV when operating in a charge-sustaining mode and equal to 4 miles per kWh when operating in a charge-depleting mode.

As is apparent from these results, the forgone fuel tax revenue will be higher when gasoline-electric hybrid vehicles displace conventional vehicles having lower fuel efficiencies. The forgone fuel tax revenue will be higher when a driver who drives more than the average purchases a HEV or a PHEV instead of a CV and when the driving behavior of the driver is not influenced by the lower marginal cost of driving a more fuel-efficient vehicle.

Aggregate Impact on Transportation Revenues

A study by the National Academy of Sciences (NAS 2009) estimates that HEVs could reach a 10-15 percent new-vehicle market share by 2020 and a 15-40 percent market share by 2035 and that PHEVs could reach a 1-3 percent new-vehicle market share by 2020 and a 7-15 percent market share by 2030. The authors of this study consider these to be "achievable deployment levels, based on historical case studies of comparable technology changes".

The forecast presented in the Annual Energy Outlook 2010 Outlook (EIA 2009) is less optimistic. EIA (2009) projects that gasoline-electric hybrids will achieve a 6 percent new-vehicle market share by 2020 and slightly over 8 percent market share by 2030; and that PHEVs will achieve less than 1 percent new-vehicle market share by 2020 and slightly over 2 percent by 2030. It also projects that total new light duty vehicles sales will be slightly over 16.5 million vehicles in 2020 and slightly less than 18 million in 2035.

We used these market penetration and sales scenarios to study the impact on combined federal and state gasoline tax revenues from the light-duty vehicle fleet. The results are presented in Table 3.2.

Table 3.2: Forgone Gasoline Tax Revenue under Different Adoption Scenarios (PV, billion $ 2009)

a: Average Fuel Economy of CV Fleet Being Displaced= 24.1 mpg

Scenario	2020			2030		
	EIA	NAS Low	NAS High	EIA	NAS Low	NAS High
HEV	0.8	1.4	2.0	1.2	2.2	5.9
PHEV-40	0.2	0.2	1.5	0.5	0.7	3.5
Sum	1.0	1.6	3.5	1.6	2.9	9.4

b: Average Fuel Economy of CV Fleet Being Displaced= 35 mpg

Scenario	2020			2030		
	EIA	NAS Low	NAS High	EIA	NAS Low	NAS High
HEV	0.2	0.4	0.6	0.3	0.6	1.7
PHEV-40	0.1	0.1	0.8	0.3	0.4	1.9
SUM	0.4	0.5	1.4	0.6	1.0	3.6

Note: numbers represent forgone federal and state gasoline tax revenues in combination.

If the fuel economy of the CV fleet that is being displaced is on average 24.1 mpg, the combined federal and states forgone gasoline tax revenues could range from 1 to 3.5 billion dollars in 2020 and from 1.6 to 9.4 in 2030 (Table 3.2 part a), and if it is on average 35 mpg, the total forgone revenue could range from 0.4 to 1.4 billion dollars in 2020 and from 0.6 to 3.6 in 2030 (Table 3.2 part b).

The National Surface Transportation Infrastructure Financing Commission projects that from 2008 to 2035 the average annual revenue flowing into the federal and state trust funds combined would be $76 billion dollars ($2009) — the flow into the Highway Trust Fund would be $32 billion dollars and into the state/local funds would be $44 billion dollars (NSTIF 2009). Thus, under the vehicle electrification scenarios projected by NAS and EIA, the combined federal and state annual revenues could decline as much as 5 percent by 2020 and as much as 12.5 percent by 2030. It is reasonable to think that the availability of these more fuel efficient vehicles and increasingly demanding federal requirements will continue to spur fuel efficiency improvements in the conventional vehicles that are sold in the marketplace, so the lost revenue from the sale of fuel is likely to be greater than these estimates.

Policy Implications

In the short term, a plausible option would be to increase rates of taxation of fuel taxes and other existing revenue sources for the Highway Trust Fund (Wachs 2003). Parry et al (2005) estimate that the optimal gasoline tax for the US is more than double its current rate. This is, of course, a political issue of enormous sensitivity. Elected officials have in many instances "promised" their constituents that they would not raise taxes, especially while the sale price of gasoline is perceived to be much higher than it was only a few years ago.

In the medium and long term however, relying on the fuel taxes as the primary source to fund transportation programs is unsustainable. To meet energy security and environmental goals, such as the reduction of greenhouse gas emissions, we need to reduce fuel consumption. Under the current transportation finance system, as long as the motor fuel tax is the principal source of transportation program revenues, there exists an incentive to increase fuel consumption. To remove the conflict between transportation financing needs and energy and environmental policies alternative transportation financing mechanisms should be considered that are not based on the amount of fuel consumed.

Historically, the motor fuel tax was adopted as an "indirect" and "second best" highway user fee because in the early days more "direct user fees" like tolls, were expensive to collect. Vehicle Miles Traveled (VMT) fees, made possible by recent advances in technology, are today being widely considered as an alternative user charge that is more consistent than fuel taxation with the goal of charging system users in relation to the benefits they receive from their use of the system (Wachs 2003; TRB 2006; NSTIF 2009; Sorensen, Ecola et al. 2009).

Under a VMT fee financing system, drivers would be charged on the basis of miles driven rather than on the basis of gallons of fuel consumed. This fee eventually could be modified in light of energy and transportation policy changes to vary with factors such as the time of day and the location at which the driving occurs, vehicle weight, or the type of fuel used by the vehicle. Because VMT is not tied to the amount of fuel consumed, more demanding fuel efficiency standards and the adoption of alternative fuels and vehicle propulsion systems would not erode revenues that are essential to the maintenance and expansion of the transportation system. Also, since fees would be directly linked to the amount of driving that takes place, the charges would contribute to greater economic efficiency in travel choice decisions.

Sorensen et al. (2009) studied the feasibility of implementing a national VMT fee in the near term future. They concluded that such implementation is becoming more feasible in terms of technology; however the administration of a VMT fee system would be more costly and complicated than that of a fuel tax. Their study suggests that it would be necessary to plan a fairly lengthy transition period during which VMT fees would first be applied to certain types of vehicles or in selected geographic areas, with larger scale adoption taking place after trials were able to prove the approaches that were most effective.

CONCLUSIONS

American energy policy and transportation policy are fundamentally in conflict with one another. In order to reduce energy consumption and production of greenhouse gases, it is necessary to make the vehicle fleet far more fuel efficient. But, in order to produce sufficient revenue to operate, maintain, and expand the transportation system under current finance models, the government depends for success upon selling large volumes of fuels.

In this paper the forgone fuel tax revenue that results when a HEV or PHEV replaces a similar-sized CV is estimated. We find that if a CV is displaced by a similar-sized PHEV-20, PHEV-40, or PHEV-60 the forgone fuel tax revenues (discounted over the life of the vehicle) are $1,100, $1,280, or $1,420, respectively. If a CV is displaced by a similar-sized HEV, the forgone fuel tax revenue is $820. These estimates are sensitive to the fuel efficiency of the CV that is being displaced, the driving patterns of the vehicle’s owner and the price elasticity of the demand for driving. Under several vehicle electrification scenarios projected by the National Academy of Sciences and the Energy Information Administration, the combined federal and state trust fund contributions could decline by as much as 5 percent by 2020 and as much as 12.5 percent by 2030. Alternative fee systems more directly tied to the use of the transportation system rather then to fuel consumption should be considered that could reconcile energy security, environmental, and transportation finance goals.

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APPENDIX A: SURVIVAL RATES (s_t) AND UTILIZATION FACTOR (α_t)

Table A.1: Survival Rates (s_t) and Utilization Factor (α_t)

Vehicle Age	s_t	Average annual miles	α_t
1	100	15,600	1
2	100	14,500	0.93
3	100	14,800	0.95
4	100	13,800	0.88
5	100	12,900	0.83
6	99.4	12,700	0.81
7	96.3	12,400	0.79
8	92.7	11,600	0.74
9	88.7	11,300	0.72
10	84.4	11,200	0.72
11	79.8	9,000	0.58
12	75.0	9,000	0.58
13	70.0	9,000	0.58
14	64.9	9,000	0.58
15	59.7	9,000	0.58
16	54.6	9,000	0.58
17	49.5	9,000	0.58
18	44.6	9,000	0.58
19	39.9	9,000	0.58
20	35.4	9,000	0.58
21	31.1	9,000	0.58
22	27.2	9,000	0.58
23	23.5	9,000	0.58
24	20.2	9,000	0.58
25	17.1	9,000	0.58
26	14.5	9,000	0.58
27	12.1	9,000	0.58
28	10.0	9,000	0.58
29	8.2	9,000	0.58
30	6.6	9,000	0.58

Source: (Davis, Diegel et al. 2009)

α_t was calculated as the average annual miles driven in year t divided by the average annual miles driven in the first year.

APPENDIX B: FUEL COST SAVINGS AND BREAKEVEN GASOLINE PRICE CALCULATIONS FOR THE FIRST ESSAY

Table B.1: Fuel Cost Savings of Passenger Cars in LowGasolinePriceHighDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=24.05	Gallons consumed mpg=25.05	Gallons saved	Fuel Cost Savings ($)****
1	100	15.600	15.600	2.64	2.10	24.05	648.65	622.75	25.89	54.4
2	100	14.500	14.500	2.76	2.10	24.05	602.91	578.84	24.07	45.9
3	100	14.800	14.800	3.13	2.10	24.05	615.38	590.82	24.57	42.6
4	100	13.800	13.800	2.23	2.10	24.05	573.80	550.90	22.91	36.1
5	100	12.900	12.900	2.16	2.10	24.05	536.38	514.97	21.41	30.7
6	99.4	12,700	12,624	2.14	2.10	24.05	524.90	503.94	20.95	27.3
7	96.3	12.400	11.941	2.05	2.10	24.05	496.52	476.69	19.82	23.5
8	92.7	11.600	10.753	2.03	2.10	24.05	447.12	429.27	17.85	19.2
9	88.7	11.300	10.023	2.00	2.10	24.05	416.76	400.12	16.64	16.3
10	84.4	11.200	9.453	1.98	2.10	24.05	393.05	377.36	15.69	14.0
11	79.8	9.000	7.182	1.99	2.10	24.05	298.63	286.71	11.92	9.7
12	75	9.000	6.750	1.99	2.10	24.05	280.67	269.46	11.20	8.2
13	70	9.000	6.300	1.99	2.10	24.05	261.95	251.50	10.46	7.0
14	64.9	9.000	5.841	1.98	2.10	24.05	242.87	233.17	9.70	5.9
15	59.7	9.000	5.373	1.98	2.10	24.05	223.41	214.49	8.92	4.9
16	54.6	9.000	4.914	1.99	2.10	24.05	204.32	196.17	8.16	4.1
17	49.5	9.000	4.455	2.01	2.10	24.05	185.24	177.84	7.39	3.4
18	44.6	9.000	4.014	2.04	2.10	24.05	166.90	160.24	6.66	2.8
19	39.9	9.000	3.591	2.00	2.10	24.05	149.31	143.35	5.96	2.3
20	35.4	9.000	3.186	2.01	2.10	24.05	132.47	127.19	5.29	1.8
21	31.1	9.000	2.799	2.01	2.10	24.05	116.38	111.74	4.65	1.5
22	27.2	9.000	2.448	2.00	2.10	24.05	101.79	97.72	4.06	1.2
23	23.5	9.000	2.115	2.00	2.10	24.05	87.94	84.43	3.51	0.9
24	20.2	9.000	1.818	2.00	2.10	24.05	75.59	72.57	3.02	0.7
25	17.1	9.000	1.539	1.99	2.10	24.05	63.99	61.44	2.55	0.5
26	14.5	9.000	1.305	1.98	2.10	24.05	54.26	52.10	2.17	0.4
27	12.1	9.000	1.089	1.97	2.10	24.05	45.28	43.47	1.81	0.3
28	10	9.000	900	1.96	2.10	24.05	37.42	35.93	1.49	0.2
29	8.2	9.000	738	1.95	2.10	24.05	30.69	29.46	1.22	0.2
30	6.6	9.000	594	1.94	2.10	24.05	24.70	23.71	0.99	0.1
									Sum	**366.2**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "Low Price Case Tables" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Table B.2: Fuel Cost Savings of Passenger Cars in MediumGasolinePriceMediumDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=24.05	Gallons consumed mpg=25.05	Gallons saved	Fuel Cost Savings ($)****
1	100	15,600	15,600	2.64	3.42	24.05	648.65	622.75	25.89	88.6
2	100	14,500	14,500	2.76	3.42	24.05	602.91	578.84	24.07	76.9
3	100	14,800	14,800	3.13	3.42	24.05	615.38	590.82	24.57	73.4
4	100	13,800	13,800	2.23	3.42	24.05	573.80	550.90	22.91	63.9
5	100	12,900	12,900	2.77	3.42	24.05	536.38	514.97	21.41	55.9
6	99.4	12,700	12,624	2.95	3.42	24.05	524.90	503.94	20.95	51.1
7	96.3	12,400	11,941	3.10	3.42	24.05	496.52	476.69	19.82	45.2
8	92.7	11,600	10,753	3.19	3.42	24.05	447.12	429.27	17.85	38.0
9	88.7	11,300	10,023	3.31	3.42	24.05	416.76	400.12	16.64	33.1
10	84.4	11,200	9,453	3.40	3.42	24.05	393.05	377.36	15.69	29.2
11	79.8	9,000	7,182	3.43	3.42	24.05	298.63	286.71	11.92	20.7
12	75	9,000	6,750	3.46	3.42	24.05	280.67	269.46	11.20	18.2
13	70	9,000	6,300	3.48	3.42	24.05	261.95	251.50	10.46	15.9
14	64.9	9,000	5,841	3.50	3.42	24.05	242.87	233.17	9.70	13.8
15	59.7	9,000	5,373	3.52	3.42	24.05	223.41	214.49	8.92	11.8
16	54.6	9,000	4,914	3.55	3.42	24.05	204.32	196.17	8.16	10.1
17	49.5	9,000	4,455	3.58	3.42	24.05	185.24	177.84	7.39	8.6
18	44.6	9,000	4,014	3.57	3.42	24.05	166.90	160.24	6.66	7.2
19	39.9	9,000	3,591	3.59	3.42	24.05	149.31	143.35	5.96	6.0
20	35.4	9,000	3,186	3.63	3.42	24.05	132.47	127.19	5.29	5.0
21	31.1	9,000	2,799	3.66	3.42	24.05	116.38	111.74	4.65	4.1
22	27.2	9,000	2,448	3.69	3.42	24.05	101.79	97.72	4.06	3.4
23	23.5	9,000	2,115	3.73	3.42	24.05	87.94	84.43	3.51	2.7
24	20.2	9,000	1,818	3.76	3.42	24.05	75.59	72.57	3.02	2.2
25	17.1	9,000	1,539	3.79	3.42	24.05	63.99	61.44	2.55	1.7
26	14.5	9,000	1,305	3.81	3.42	24.05	54.26	52.10	2.17	1.4
27	12.1	9,000	1,089	3.83	3.42	24.05	45.28	43.47	1.81	1.1
28	10	9,000	900	3.85	3.42	24.05	37.42	35.93	1.49	0.8
29	8.2	9,000	738	3.87	3.42	24.05	30.69	29.46	1.22	0.6
30	6.6	9,000	594	3.89	3.42	24.05	24.70	23.71	0.99	0.5
									sum	**691**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "Year-by-Year Reference Case Tables (2006-2030)" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Table B.3: Fuel Cost Savings of Passenger Cars in HighGasolinePriceLowDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=24.05	Gallons consumed mpg=25.05	Gallons saved	Fuel Cost Savings ($)****
1	100	15.600	15.600	2.64	4.52	24.05	648.65	622.75	25.89	117.0
2	100	14.500	14.500	2.76	4.52	24.05	602.91	578.84	24.07	105.6
3	100	14.800	14.800	3.13	4.52	24.05	615.38	590.82	24.57	104.7
4	100	13.800	13.800	2.23	4.52	24.05	573.80	550.90	22.91	94.8
5	100	12.900	12.900	3.01	4.52	24.05	536.38	514.97	21.41	86.0
6	99.4	12.700	12.624	3.28	4.52	24.05	524.90	503.94	20.95	81.7
7	96.3	12.400	11.941	3.54	4.52	24.05	496.52	476.69	19.82	75.0
8	92.7	11.600	10.753	3.82	4.52	24.05	447.12	429.27	17.85	65.6
9	88.7	11.300	10.023	4.14	4.52	24.05	416.76	400.12	16.64	59.4
10	84.4	11.200	9.453	4.39	4.52	24.05	393.05	377.36	15.69	54.4
11	79.8	9.000	7.182	4.55	4.52	24.05	298.63	286.71	11.92	40.1
12	75	9.000	6.750	4.73	4.52	24.05	280.67	269.46	11.20	36.6
13	70	9.000	6.300	4.82	4.52	24.05	261.95	251.50	10.46	33.2
14	64.9	9.000	5.841	4.89	4.52	24.05	242.87	233.17	9.70	29.8
15	59.7	9.000	5.373	4.93	4.52	24.05	223.41	214.49	8.92	26.7
16	54.6	9.000	4.914	4.92	4.52	24.05	204.32	196.17	8.16	23.7
17	49.5	9.000	4.455	4.96	4.52	24.05	185.24	177.84	7.39	20.8
18	44.6	9.000	4.014	5.02	4.52	24.05	166.90	160.24	6.66	18.2
19	39.9	9.000	3.591	5.03	4.52	24.05	149.31	143.35	5.96	15.8
20	35.4	9.000	3.186	5.08	4.52	24.05	132.47	127.19	5.29	13.6
21	31.1	9.000	2.799	5.14	4.52	24.05	116.38	111.74	4.65	11.6
22	27.2	9.000	2.448	5.18	4.52	24.05	101.79	97.72	4.06	9.9
23	23.5	9.000	2.115	5.24	4.52	24.05	87.94	84.43	3.51	8.3
24	20.2	9.000	1.818	5.29	4.52	24.05	75.59	72.57	3.02	6.9
25	17.1	9.000	1.539	5.35	4.52	24.05	63.99	61.44	2.55	5.7
26	14.5	9.000	1.305	5.40	4.52	24.05	54.26	52.10	2.17	4.7
27	12.1	9.000	1.089	5.45	4.52	24.05	45.28	43.47	1.81	3.8
28	10	9.000	900	5.51	4.52	24.05	37.42	35.93	1.49	3.0
29	8.2	9.000	738	5.56	4.52	24.05	30.69	29.46	1.22	2.4
30	6.6	9.000	594	5.62	4.52	24.05	24.70	23.71	0.99	1.9
									sum	**1160.8**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "High Price Case Tables" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Table B.4: Fuel Cost Savings of Light Trucks and SUVs in LowGasolinePriceHighDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=19.23	Gallons consumed mpg=20.23	Gallons saved	Fuel Cost Savings ($)****
1	100	17,500	17,500	2.64	2.10	19.23	910.0	865.1	45.0	94.5
2	100	19,200	19,200	2.76	2.10	19.23	998.4	949.1	49.4	94.2
3	100	19,800	19,800	3.13	2.10	19.23	1029.6	978.7	50.9	88.3
4	100	17,900	17,900	2.23	2.10	19.23	930.8	884.8	46.0	72.6
5	96.9	17,500	16,957	2.16	2.10	19.23	881.8	838.2	43.6	62.5
6	94.1	17,000	15,997	2.14	2.10	19.23	831.9	790.8	41.1	53.6
7	90.7	15,600	14,149	2.05	2.10	19.23	735.8	699.4	36.4	43.1
8	86.9	15,400	13,382	2.03	2.10	19.23	695.9	661.5	34.4	37.1
9	82.7	15,100	12,488	2.00	2.10	19.23	649.4	617.3	32.1	31.4
10	78.2	13,200	10,322	1.98	2.10	19.23	536.8	510.3	26.5	23.6
11	73.4	9,200	6,753	1.99	2.10	19.23	351.2	333.8	17.4	14.1
12	68.4	9,200	6,293	1.99	2.10	19.23	327.2	311.1	16.2	11.9
13	63.3	9,200	5,824	1.99	2.10	19.23	302.8	287.9	15.0	10.0
14	58	9,200	5,336	1.98	2.10	19.23	277.5	263.8	13.7	8.3
15	52.8	9,200	4,858	1.98	2.10	19.23	252.6	240.1	12.5	6.9
16	47.7	9,200	4,388	1.99	2.10	19.23	228.2	216.9	11.3	5.7
17	42.7	9,200	3,928	2.01	2.10	19.23	204.3	194.2	10.1	4.6
18	37.9	9,200	3,487	2.04	2.10	19.23	181.3	172.4	9.0	3.7
19	33.3	9,200	3,064	2.00	2.10	19.23	159.3	151.4	7.9	3.0
20	29	9,200	2,668	2.01	2.10	19.23	138.7	131.9	6.9	2.4
21	25	9,200	2,300	2.01	2.10	19.23	119.6	113.7	5.9	1.8
22	21.4	9,200	1,969	2.00	2.10	19.23	102.4	97.3	5.1	1.4
23	18.1	9,200	1,665	2.00	2.10	19.23	86.6	82.3	4.3	1.1
24	15.2	9,200	1,398	2.00	2.10	19.23	72.7	69.1	3.6	0.8
25	12.6	9,200	1,159	1.99	2.10	19.23	60.3	57.3	3.0	0.6
26	10.3	9,200	948	1.98	2.10	19.23	49.3	46.8	2.4	0.5
27	8.4	9,200	773	1.97	2.10	19.23	40.2	38.2	2.0	0.4
28	6.7	9,200	616	1.96	2.10	19.23	32.1	30.5	1.6	0.3
29	5.3	9,200	488	1.95	2.10	19.23	25.4	24.1	1.3	0.2
30	4.2	9,200	386	1.94	2.10	19.23	20.1	19.1	1.0	0.1
									sum	**678.8**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "Low Price Case Tables" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Table B.5: Fuel Cost Savings of Light Trucks and SUVs in MediumGasolinePriceMediumDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=19.23	Gallons consumed mpg=20.23	Gallons saved	Fuel Cost Savings ($)****
1	100	17,500	17,500	2.64	3.42	19.23	910.0	865.1	45.0	153.8
2	100	19,200	19,200	2.76	3.42	19.23	998.4	949.1	49.4	157.7
3	100	19,800	19,800	3.13	3.42	19.23	1029.6	978.7	50.9	152.0
4	100	17,900	17,900	2.23	3.42	19.23	930.8	884.8	46.0	128.5
5	96.9	17,500	16,957	2.77	3.42	19.23	881.8	838.2	43.6	113.7
6	94.1	17,000	15,997	2.95	3.42	19.23	831.9	790.8	41.1	100.3
7	90.7	15,600	14,149	3.10	3.42	19.23	735.8	699.4	36.4	82.9
8	86.9	15,400	13,382	3.19	3.42	19.23	695.9	661.5	34.4	73.3
9	82.7	15,100	12,488	3.31	3.42	19.23	649.4	617.3	32.1	63.9
10	78.2	13,200	10,322	3.40	3.42	19.23	536.8	510.3	26.5	49.4
11	73.4	9,200	6,753	3.43	3.42	19.23	351.2	333.8	17.4	30.2
12	68.4	9,200	6,293	3.46	3.42	19.23	327.2	311.1	16.2	26.3
13	63.3	9,200	5,824	3.48	3.42	19.23	302.8	287.9	15.0	22.7
14	58	9,200	5,336	3.50	3.42	19.23	277.5	263.8	13.7	19.5
15	52.8	9,200	4,858	3.52	3.42	19.23	252.6	240.1	12.5	16.6
16	47.7	9,200	4,388	3.55	3.42	19.23	228.2	216.9	11.3	14.0
17	42.7	9,200	3,928	3.58	3.42	19.23	204.3	194.2	10.1	11.7
18	37.9	9,200	3,487	3.57	3.42	19.23	181.3	172.4	9.0	9.7
19	33.3	9,200	3,064	3.59	3.42	19.23	159.3	151.4	7.9	8.0
20	29	9,200	2,668	3.63	3.42	19.23	138.7	131.9	6.9	6.5
21	25	9,200	2,300	3.66	3.42	19.23	119.6	113.7	5.9	5.2
22	21.4	9,200	1,969	3.69	3.42	19.23	102.4	97.3	5.1	4.2
23	18.1	9,200	1,665	3.73	3.42	19.23	86.6	82.3	4.3	3.3
24	15.2	9,200	1,398	3.76	3.42	19.23	72.7	69.1	3.6	2.6
25	12.6	9,200	1,159	3.79	3.42	19.23	60.3	57.3	3.0	2.0
26	10.3	9,200	948	3.81	3.42	19.23	49.3	46.8	2.4	1.5
27	8.4	9,200	773	3.83	3.42	19.23	40.2	38.2	2.0	1.2
28	6.7	9,200	616	3.85	3.42	19.23	32.1	30.5	1.6	0.9
29	5.3	9,200	488	3.87	3.42	19.23	25.4	24.1	1.3	0.6
30	4.2	9,200	386	3.89	3.42	19.23	20.1	19.1	1.0	0.5
									Sum	**1262.6**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "Year-by-Year Reference Case Tables (2006-2030)" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Table B.6: Fuel Cost Savings of Light Trucks and SUVs in HighGasolinePriceLowDiscountRate Scenario

Vehicle age (year)*	Survival rate*	Average annual miles*	Miles given survival	Gasoline price ($)***	Average gasoline price ($)	Average 2006 models' FE(mpg)	Gallons consumed mpg=19.23	Gallons consumed mpg=20.23	Gallons saved	Fuel Cost Savings ($)****
1	100	17,500	17,500	2.64	4.52	19.23	910.0	865.1	45.0	203.3
2	100	19,200	19,200	2.76	4.52	19.23	998.4	949.1	49.4	216.6
3	100	19,800	19,800	3.13	4.52	19.23	1029.6	978.7	50.9	216.8
4	100	17,900	17,900	2.23	4.52	19.23	930.8	884.8	46.0	190.3
5	96.9	17,500	16,957	3.01	4.52	19.23	881.8	838.2	43.6	175.1
6	94.1	17,000	15,997	3.28	4.52	19.23	831.9	790.8	41.1	160.3
7	90.7	15,600	14,149	3.54	4.52	19.23	735.8	699.4	36.4	137.7
8	86.9	15,400	13,382	3.82	4.52	19.23	695.9	661.5	34.4	126.4
9	82.7	15,100	12,488	4.14	4.52	19.23	649.4	617.3	32.1	114.5
10	78.2	13,200	10,322	4.39	4.52	19.23	536.8	510.3	26.5	91.9
11	73.4	9,200	6,753	4.55	4.52	19.23	351.2	333.8	17.4	58.4
12	68.4	9,200	6,293	4.73	4.52	19.23	327.2	311.1	16.2	52.8
13	63.3	9,200	5,824	4.82	4.52	19.23	302.8	287.9	15.0	47.5
14	58	9,200	5,336	4.89	4.52	19.23	277.5	263.8	13.7	42.2
15	52.8	9,200	4,858	4.93	4.52	19.23	252.6	240.1	12.5	37.3
16	47.7	9,200	4,388	4.92	4.52	19.23	228.2	216.9	11.3	32.7
17	42.7	9,200	3,928	4.96	4.52	19.23	204.3	194.2	10.1	28.4
18	37.9	9,200	3,487	5.02	4.52	19.23	181.3	172.4	9.0	24.5
19	33.3	9,200	3,064	5.03	4.52	19.23	159.3	151.4	7.9	20.9
20	29	9,200	2,668	5.08	4.52	19.23	138.7	131.9	6.9	17.7
21	25	9,200	2,300	5.14	4.52	19.23	119.6	113.7	5.9	14.8
22	21.4	9,200	1,969	5.18	4.52	19.23	102.4	97.3	5.1	12.3
23	18.1	9,200	1,665	5.24	4.52	19.23	86.6	82.3	4.3	10.1
24	15.2	9,200	1,398	5.29	4.52	19.23	72.7	69.1	3.6	8.2
25	12.6	9,200	1,159	5.35	4.52	19.23	60.3	57.3	3.0	6.6
26	10.3	9,200	948	5.40	4.52	19.23	49.3	46.8	2.4	5.3
27	8.4	9,200	773	5.45	4.52	19.23	40.2	38.2	2.0	4.2
28	6.7	9,200	616	5.51	4.52	19.23	32.1	30.5	1.6	3.2
29	5.3	9,200	488	5.56	4.52	19.23	25.4	24.1	1.3	2.5
30	4.2	9,200	386	5.62	4.52	19.23	20.1	19.1	1.0	1.9
									sum	**2064.6**

*(Davis, S. C., et al. 2008); ** Gasoline price projections are taken from "High Price Case Tables" from Annual Energy Outlook 2009 (EIA 2009); *** Used US CPI all items less food and energy (Bureau of Labor Statistics no date); ****discount rate 10%; $ are in 2006 values.

Breakeven Gasoline Price Calculations: An average breakeven gasoline price is one that results in the same fuel cost savings and implicit cost of improving fuel efficiency. To calculate the average breakeven gasoline price, Table A.1-A.6 are generated for various average gasoline prices. Results are presented in Table A.7-A.12.

Table B.7: Breakeven Gasoline Price for Passenger Cars if Fuel Efficiency Improves via HP Reduction, LowGasolinePriceHighDiscountRate Scenario, ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	6,347	0	6,347
3	6,347	523	5,824
6	6,347	1,046	5,301
9	6,347	1,570	4,777
12	6,347	2,093	4,254
15	6,347	2,616	3,731
18	6,347	3,139	3,208
21	6,347	3,662	2,685
24	6,347	4,185	2,162
27	6,347	4,709	1,638
30	6,347	5,232	1,115
33	6,347	5,755	592
36	6,347	6,278	69
36.4	6,347	6,348	-1
39	6,347	6,801	-454

*from Table 7; **using Table A.1

Table B.8: Breakeven Gasoline Price for Passenger Cars if Fuel Efficiency Improves via Weight Reduction, LowGasolinePriceHighDiscountRate Scenario ($2006)

Average Gasoline Price	A:Net Implicit Cost*	B:Fuel Cost Savings**	A-B
0	2,336	0	2,336
1.5	2,336	262	2,074
2.5	2,336	436	1,900
3.5	2,336	610	1,726
4.5	2,336	785	1,551
5.5	2,336	959	1,377
6.5	2,336	1,134	1,202
7.5	2,336	1,308	1,028
8.5	2,336	1,482	854
9.5	2,336	1,657	679
10.5	2,336	1,831	505
11.5	2,336	2,006	330
12.5	2,336	2,180	156
13.4	2,336	2,337	-1
13.5	2,336	2,354	-18

*from Table 7, **using Table A.1

Table B.9: Breakeven Gasoline Price for Passenger Cars if Fuel Efficiency Improves via HP Reduction, MediumGasolinePriceMediumDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	6,347	0	6,347
3	6,347	606	5,741
6	6,347	1,212	5,135
9	6,347	1,818	4,529
12	6,347	2,425	3,922
15	6,347	3,031	3,316
18	6,347	3,637	2,710
21	6,347	4,243	2,104
24	6,347	4,849	1,498
27	6,347	5,455	892
30	6,347	6,062	285
31.42	6,347	6,348	-1
33	6,347	6,668	-321
36	6,347	7,274	-927
39	6,347	7,880	-1533

*from Table 7, **using Table A.2

Table B.10: Breakeven Gasoline Price for Passenger cars if Fuel Efficiency Improves via Weight Reduction, MediumGasolinePriceMediumDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	2,336	0	2,336
1	2,336	202	2,134
2	2,336	404	1,932
3	2,336	606	1,730
4	2,336	808	1,528
5	2,336	1,010	1,326
6	2,336	1,212	1,124
7	2,336	1,414	922
8	2,336	1,616	720
9	2,336	1,818	518
10	2,336	2,021	315
11	2,336	2,223	113
11.56	2,336	2,336	0
12	2,336	2,425	-89
13	2,336	2,627	-291

*from Table 7, **using Table A.2

Table B.11: Breakeven Gasoline Price for Passenger cars if Fuel Efficiency Improves via HP Reduction, HighGasolinePriceLowDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	6,347	0	6,347
3	6,347	770	5,577
6	6,347	1,541	4,806
9	6,347	2,311	4,036
12	6,347	3,082	3,265
15	6,347	3,852	2,495
18	6,347	4,623	1,724
21	6,347	5,393	954
24	6,347	6,164	183
24.72	6,347	6,348	-1
27	6,347	6,934	-587
30	6,347	7,704	-1,357
33	6,347	8,475	-2,128
36	6,347	9,245	-2,898
39	6,347	10,016	-3,669

*from Table 7, **using Table A.3

Table B.12: Breakeven Gasoline Price for Passenger cars if Fuel Efficiency Improves via Weight Reduction, HighGasolinePriceLowDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	2336	0	2,336
1	2336	257	2,079
2	2336	514	1,822
3	2336	770	1,566
4	2336	1027	1,309
5	2336	1284	1,052
6	2336	1541	795
7	2336	1798	538
8	2336	2055	281
9	2336	2311	25
9.1	2336	2337	-1
10	2336	2568	-232
11	2336	2825	-489
12	2336	3082	-746
13	2336	3339	-1,003

*from Table 7, **using Table A.3

Table B.13: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via HP Reduction, LowGasolinePriceHighDiscountRate Scenario, ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	3,033	0	3033
1	3,033	323	2,710
2	3,033	647	2,386
3	3,033	970	2,063
4	3,033	1,293	1,740
5	3,033	1,616	1,417
6	3,033	1,940	1,093
7	3,033	2,263	770
8	3,033	2,586	447
9	3,033	2,909	124
9.38	3,033	3,032	1
10	3,033	3,233	-200
11	3,033	3,556	-523
12	3,033	3,879	-846
13	3,033	4,202	-1,169

*from Table 7, **using Table A.4

Table B.14: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via Weight Reduction, LowGasolinePriceHighDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	1,461	0	1,461
0.5	1,461	162	1,299
1.5	1,461	485	976
2.5	1,461	808	653
3.5	1,461	1,131	330
4.5	1,461	1,455	6
4.52	1,461	1,461	0
5.5	1,461	1,778	-317
6.5	1,461	2,101	-640
7.5	1,461	2,424	-963
8.5	1,461	2,748	-1,287
9.5	1,461	3,071	-1,610
10.5	1,461	3,394	-1,933
11.5	1,461	3,717	-2,256
12.5	1,461	4,041	-2,580

*from Table 7, **using Table A.4

Table B.15: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via HP Reduction, MediumGasolinePriceMediumDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	3,033	0	3,033
1	3,033	369	2,664
2	3,033	738	2,295
3	3,033	1,108	1,925
4	3,033	1,477	1,556
5	3,033	1,846	1,187
6	3,033	2,215	818
7	3,033	2,584	449
8	3,033	2,953	80
8.21	3,033	3,031	2
9	3,033	3,323	-290
10	3,033	3,692	-659
11	3,033	4,061	-1,028
12	3,033	4,430	-1,397
13	3,033	4,799	-1,766

*from Table 7, **using Table A.5

Table B.16: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via Weight Reduction, MediumGasolinePriceMediumDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	1461	0	1461
0.4	1461	148	1313
0.8	1461	295	1166
1.2	1461	443	1018
1.6	1461	591	870
2	1461	738	723
2.4	1461	886	575
2.8	1461	1034	427
3.2	1461	1181	280
3.6	1461	1329	132
3.96	1461	1462	-1
4	1461	1477	-16
4.4	1461	1624	-163
4.8	1461	1772	-311
5.2	1461	1920	-459

*from Table 7, **using Table A.5

Table B.17: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via HP Reduction, HighGasolinePriceLowDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	3033	0	3033
1	3033	457	2576
2	3033	914	2119
3	3033	1370	1663
4	3033	1827	1206
5	3033	2284	749
6	3033	2741	292
6.64	3033	3033	0
7	3033	3197	-164
8	3033	3654	-621
9	3033	4111	-1078
10	3033	4568	-1535
11	3033	5024	-1991
12	3033	5481	-2448
13	3033	5938	-2905

*from Table 7, **using Table A.6

Table B.18: Breakeven Gasoline Price for Light Trucks and SUVs if Fuel Efficiency Improves via Weight Reduction, HighGasolinePriceLowDiscountRate Scenario ($2006)

Average Gasoline Price	A: Net Implicit Cost*	B: Fuel Cost Savings**	A-B
0	1461	0	1461
0.4	1461	183	1278
0.8	1461	365	1096
1.2	1461	548	913
1.6	1461	731	730
2	1461	914	547
2.4	1461	1096	365
2.8	1461	1279	182
3.2	1461	1462	-1
3.6	1461	1644	-183
4	1461	1827	-366
4.4	1461	2010	-549
4.8	1461	2192	-731
5.2	1461	2375	-914

*from Table 7, **using Table A.6

APPENDIX C: VMT DISTRIBUTIONS

Table C.1 presents the values of the i-quantile for different VMT distributions in miles.

Table C.1: i-quantile VMT distribution (miles)

i	Probability	i-quantile for low VMT distribution	i-quantile for medium VMT distribution	i-quantile for high VMT distribution
1	0-5%	1	1	1
2	5-10%	1	1	1
3	10-15%	2	2	2
4	15-20%	3	3	3
5	20-25%	4	4	4
6	25-30%	5	5	5
7	30-35%	7	7	7
8	35-40%	8	9	10
9	40-45%	10	11	12
10	45-50%	12	14	15
11	50-55%	15	18	20
12	55-60%	18	22	25
13	60-65%	20	29	31
14	65-70%	25	35	40
15	70-75%	30	42	51
16	75-80%	38	52	64
17	80-85%	46	62	82
18	85-90%	60	80	107
19	90-95%	83	106	148
20	95-100%	131	170	228

As an illustrative example, consider a PHEV-40 which follows the medium VMT distribution shown in Table C.1. For days on which the total miles are fewer than 36 (40*0.8) miles, all of the VMT are driven powered by electricity. For days in which the total miles are more than 36, the first 36 miles are driven powered by electricity and the remainder by gasoline. For example, some 5% of the time the vehicle is driven less than 4 miles (1-quantile), and thus, all on electricity. However, another 5% of the time the vehicle is driven about 177 miles (20-quantile). Thus, the first 36 miles is on electricity and the rest (141 miles) is driven on gasoline.

APPENDIX D: DETAILED RESULTS OF THE SENSITIVITY ANALYSIS FOR THE SECOND ESSAY

Changes in Private Surplus Relative to CV

Table D.1: Sensitivity of Changes in Private Surplus Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	68%	-61%	51%	-46%	49%	-44%	48%	-43%	57%	-52%
Price of gasoline	$/gallon	1.5	2.5	4.5	-40%	80%	-50%	100%	-52%	104%	-52%	106%	-66%	135%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	10%	-38%	12%	-43%	13%	-46%	18%	-61%
Change in Price of Gasoline*	-	0.99	1	1.01	-3%	6%	-4%	8%	-4%	8%	-4%	8%	-5%	10%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	1%	-2%	1%	-2%	1%	-3%	2%	-4%
Discount Rate	-	3%	7%	10	27%	-14%	27%	-14%	27%	-14%	27%	-14%	33%	-17%
VMT Elasticity	-	-0.05	-0.15	-0.25	-3%	3%	-4%	4%	-4%	4%	-4%	5%	-7%	7%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	27%	-21%	26%	-21%	26%	-22%	26%	-28%	33%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.2: Changes in Private Surplus Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	9,060	5,390	2,100	10,950	7,230	3,870	11,350	7,600	4,230	11,570	7,810	4,420	10,480	6,690	3,240
Price of gasoline	$/gallon	1.5	2.5	4.5	3,230	5,390	9,700	3,600	7,230	14,490	3,670	7,600	15,500	3,710	7,810	16,070	2,280	6,690	15,700
Price of electricity	$/kWh	0.06	0.1	0.25	5,390	5,390	5,390	7,970	7,230	4,490	8,510	7,600	4,320	8,810	7,810	4,230	7,910	6,690	2,590
Change in Price of Gasoline*	-	0.99	1	1.01	5,240	5,390	5,720	6,970	7,230	7,780	7,320	7,600	8,220	7,510	7,810	8,460	6,360	6,690	7,390
Change in Price of Electricity*	-	0.99	1	1.01	5,390	5,390	5,390	7,300	7,230	7,080	7,690	7,600	7,420	7,910	7,810	7,610	6,800	6,690	6,450
Discount	-	3%	7%	10%	6,850	5,390	4,650	9,190	7,230	6,240	9,670	7,600	6,560	9,930	7,810	6,740	8,910	6,690	5,560
VMT Elasticity	-	-0.05	-0.15	-0.25	5,220	5,390	5,570	6,950	7,230	7,510	7,290	7,600	7,940	7,460	7,810	8,180	6,240	6,690	7,170
VMT distribution	-	Low VMT	Medium VMT	VMT High	4,160	5,390	6,870	5,690	7,230	9,110	5,990	7,600	9,570	6,120	7,810	9,810	4,820	6,690	8,900
Nuclear	-	-	-	-	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
NGCC	-	-	-	-	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
COAL	-	-	-	-	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
VOC	$/ton	210	1,090	1,980	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
CO emissions	$/ton	20	90	160	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
NOX	$/ton	1,710	6,350	10,740	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
PM10	$/ton	11,430	20,260	29,100	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
PM2.5	$/ton	21,630	173,860	326,100	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
SOX	$/ton	6,980	31,490	56,000	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
GHGs	$/ton CO2-equevalent	1.5	14	70	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
Energy Security	$/gallon	0.02	0.37	0.63	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690
Congestion	$/mile	0.02	0.035	0.09	5,390	5,390	5,390	7,230	7,230	7,230	7,600	7,600	7,600	7,810	7,810	7,810	6,690	6,690	6,690

*relative to the price of other goods and services

Fuel Cost Savings Relative to CV

Table D.3: Sensitivity of Fuel Cost Savings Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	65%	-60%	52%	-47%	49%	-43%	48%	-44%	59%	-54%
Price of gasoline	$/gallon	1.5	2.5	4.5	-40%	80%	-50%	100%	-52%	104%	-53%	106%	-69%	140%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	10%	-38%	12%	-43%	13%	-46%	19%	-64%
Change in Price of Gasoline*	-	0.99	1	1.01	-3%	6%	-4%	8%	-4%	9%	-4%	9%	-5%	11%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	1%	-2%	1%	-2%	1%	-2%	1%	-3%
Discount Rate	-	3%	7%	10	27%	-14%	27%	-14%	27%	-14%	27%	-14%	34%	-18%
VMT Elasticity	-	-0.05	-0.15	-0.25	12%	-12%	7%	-8%	7%	-8%	7%	-8%	7%	-8%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	27%	-21%	26%	-21%	26%	-22%	26%	-29%	34%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.4: Fuel Cost Savings Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	7,220	4,370	1,740	9,310	6,140	3,280	9,650	6,460	3,650	9,830	6,640	3,750	8,680	5,460	2,530
Price of gasoline	$/gallon	1.5	2.5	4.5	2,620	4,370	7,860	3,060	6,140	12,310	3,120	6,460	13,170	3,150	6,640	13,650	1,710	5,460	13,120
Price of electricity	$/kWh	0.06	0.1	0.25	4,370	4,370	4,370	6,770	6,140	3,820	7,230	6,460	3,670	7,490	6,640	3,590	6,500	5,460	1,970
Change in Price of Gasoline*	-	0.99	1	1.01	4,240	4,370	4,630	5,900	6,140	6,660	6,200	6,460	7,020	6,360	6,640	7,220	5,160	5,460	6,080
Change in Price of Electricity*	-	0.99	1	1.01	4,370	4,370	4,370	6,190	6,140	6,030	6,520	6,460	6,330	6,710	6,640	6,490	5,540	5,460	5,280
Discount Rate	-	3%	7%	10%	5,550	4,370	3,770	7,800	6,140	5,300	8,210	6,460	5,580	8,440	6,640	5,730	7,340	5,460	4,500
VMT Elasticity	-	-0.05	-0.15	-0.25	4,880	4,370	3,850	6,600	6,140	5,630	6,920	6,460	5,950	7,090	6,640	6,130	5,850	5,460	5,000
VMT distribution	-	Low VMT	Medium VMT	VMT High	3,370	4,370	5,560	4,840	6,140	7,740	5,090	6,460	8,130	5,200	6,640	8,340	3,870	5,460	7,340
Nuclear	-	-	-	-	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
NGCC	-	-	-	-	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
COAL	-	-	-	-	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
VOC emissions	$/ton	210	1,090	1,980	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
CO emissions	$/ton	20	90	160	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
NOX emissions	$/ton	1,710	6,350	10,740	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
PM10	$/ton	11,430	20,260	29,100	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
PM2.5	$/ton	21,630	173,860	326,100	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
SOX emissions	$/ton	6,980	31,490	56,000	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
GHGs	$/ton CO2-equevalent	1.5	14	70	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
Energy Security	$/gallon	0.02	0.37	0.63	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460
Congestion	$/mile	0.02	0.035	0.09	4,370	4,370	4,370	6,140	6,140	6,140	6,460	6,460	6,460	6,640	6,640	6,640	5,460	5,460	5,460

*relative to the price of other goods and services

Criteria Air Pollutants Reduction Benefit Relative to CV

Table D.5: Sensitivity of Criteria Air Pollutants Reduction Benefit Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-500%	200%	100%	-100%	100%	-80%	71%	-57%	73%	-45%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	-67%	33%	-60%	60%	-43%	43%	-36%	55%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	33%	-133%	40%	-100%	29%	-86%	45%	-64%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	0%	0%	0%	0%	-14%	0%	0%	9%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	0%	-33%	0%	0%	0%	-14%	9%	0%
Discount Rate	-	3%	7%	10	0%	0%	0%	-33%	20%	-20%	14%	-14%	27%	-9%
VMT Elasticity	-	-0.05	-0.15	-0.25	400%	-400%	-167%	167%	-120%	120%	-86%	86%	-64%	82%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	0%	0%	0%	0%	-14%	0%	-18%	27%
Nuclear	-	-	-	-	0%	0%	-433%	-433%	-400%	-400%	-386%	-386%	-409%	-409%
NGCC	-	-	-	-	0%	0%	-333%	-333%	-320%	-320%	-286%	-286%	-309%	-309%
COAL	-	-	-	-	0%	0%	267%	267%	280%	280%	257%	257%	300%	300%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	-33%	20%	-20%	14%	-14%	18%	-9%
CO emissions	$/ton	20	90	160	0%	0%	0%	-33%	20%	-20%	0%	-14%	18%	-9%
NOX emissions	$/ton	1,710	6,350	10,740	-100%	0%	0%	-33%	20%	-20%	14%	-14%	18%	-9%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	-14%	9%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	100%	-100%	33%	-67%	60%	-60%	57%	-57%	73%	-73%
SOX emissions	$/ton	6,980	31,490	56,000	-100%	100%	-167%	167%	-180%	180%	-171%	171%	-191%	200%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.6: Criteria Air Pollutants Reduction Benefit Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-40	10	30	-60	-30	0	-100	-50	-10	-120	-70	-30	-190	-110	-60
Price of gasoline	$/gallon	1.5	2.5	4.5	10	10	10	-10	-30	-40	-20	-50	-80	-40	-70	-100	-70	-110	-170
Price of electricity	$/kWh	0.06	0.1	0.25	10	10	10	-40	-30	10	-70	-50	0	-90	-70	-10	-160	-110	-40
Change in Price of Gasoline*	-	0.99	1	1.01	10	10	10	-30	-30	-30	-50	-50	-50	-60	-70	-70	-110	-110	-120
Change in Price of Electricity*	-	0.99	1	1.01	10	10	10	-30	-30	-20	-50	-50	-50	-70	-70	-60	-120	-110	-110
Discount Rate	-	3%	7%	10%	10	10	10	-30	-30	-20	-60	-50	-40	-80	-70	-60	-140	-110	-100
VMT Elasticity	-	-0.05	-0.15	-0.25	50	10	-30	20	-30	-80	10	-50	-110	-10	-70	-130	-40	-110	-200
VMT distribution	-	Low VMT	Medium VMT	VMT High	10	10	10	-30	-30	-30	-50	-50	-50	-60	-70	-70	-90	-110	-140
Nuclear	-	-	-	-	10	10	10	100	-30	100	150	-50	150	200	-70	200	340	-110	340
NGCC	-	-	-	-	10	10	10	70	-30	70	110	-50	110	130	-70	130	230	-110	230
COAL	-	-	-	-	10	10	10	-110	-30	-110	-190	-50	-190	-250	-70	-250	-440	-110	-440
VOC emissions	$/ton	210	1,090	1,980	10	10	10	-30	-30	-20	-60	-50	-40	-80	-70	-60	-130	-110	-100
CO emissions	$/ton	20	90	160	10	10	10	-30	-30	-20	-60	-50	-40	-70	-70	-60	-130	-110	-100
NOX emissions	$/ton	1,710	6,350	10,740	0	10	10	-30	-30	-20	-60	-50	-40	-80	-70	-60	-130	-110	-100
PM10 emissions	$/ton	11,430	20,260	29,100	10	10	10	-30	-30	-30	-50	-50	-50	-70	-70	-60	-120	-110	-110
PM2.5 emissions	$/ton	21,630	173,860	326,100	20	10	0	-40	-30	-10	-80	-50	-20	-110	-70	-30	-190	-110	-30
SOX emissions	$/ton	6,980	31,490	56,000	0	10	20	20	-30	-80	40	-50	-140	50	-70	-190	100	-110	-330
GHGs	$/ton CO2-equevalent	1.5	14	70	10	10	10	-30	-30	-30	-50	-50	-50	-70	-70	-70	-110	-110	-110
Energy Security	$/gallon	0.02	0.37	0.63	10	10	10	-30	-30	-30	-50	-50	-50	-70	-70	-70	-110	-110	-110
Congestion	$/mile	0.02	0.035	0.09	10	10	10	-30	-30	-30	-50	-50	-50	-70	-70	-70	-110	-110	-110

*relative to the price of other goods and services

GHG Emissions Reduction Benefit Relative to CV

Table D.7: Sensitivity of GHG Emissions Reduction Benefit Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-30%	0%	11%	-11%	0%	-11%	-11%	-11%	0%	0%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	33%	-11%	33%	-33%	33%	-44%	50%	-50%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-11%	44%	-22%	56%	-33%	56%	-50%	88%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	11%	0%	0%	-11%	0%	-11%	13%	0%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	0%	11%	0%	0%	-11%	0%	0%	13%
Discount Rate	-	3%	7%	10	30%	-10%	33%	-11%	22%	-11%	22%	-22%	38%	-13%
VMT Elasticity	-	-0.05	-0.15	-0.25	50%	-50%	67%	-56%	67%	-78%	67%	-78%	88%	-100%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-20%	30%	-22%	33%	-22%	22%	-22%	22%	-25%	38%
Nuclear	-	-	-	-	0%	0%	156%	156%	244%	244%	322%	322%	638%	638%
NGCC	-	-	-	-	0%	0%	22%	22%	33%	33%	44%	44%	100%	100%
COAL	-	-	-	-	0%	0%	-100%	-100%	-167%	-167%	-222%	-222%	-413%	-413%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	-90%	400%	-89%	422%	-89%	389%	-89%	378%	-88%	413%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.8: GHG Emissions Reduction Benefit Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	70	100	100	100	90	80	90	90	80	80	90	80	80	80	80
Price of gasoline	$/gallon	1.5	2.5	4.5	100	100	100	120	90	80	120	90	60	120	90	50	120	80	40
Price of electricity	$/kWh	0.06	0.1	0.25	100	100	100	80	90	130	70	90	140	60	90	140	40	80	150
Change in Price of Gasoline*	-	0.99	1	1.01	100	100	100	100	90	90	90	90	80	90	90	80	90	80	80
Change in Price of Electricity*	-	0.99	1	1.01	100	100	100	90	90	100	90	90	90	80	90	90	80	80	90
Discount Rate	-	3%	7%	10%	130	100	90	120	90	80	110	90	80	110	90	70	110	80	70
VMT Elasticity	-	-0.05	-0.15	-0.25	150	100	50	150	90	40	150	90	20	150	90	20	150	80	0
VMT distribution	-	Low VMT	Medium VMT	VMT High	80	100	130	70	90	120	70	90	110	70	90	110	60	80	110
Nuclear	-	-	-	-	100	100	100	230	90	230	310	90	310	380	90	380	590	80	590
NGCC	-	-	-	-	100	100	100	110	90	110	120	90	120	130	90	130	160	80	160
COAL	-	-	-	-	100	100	100	0	90	0	-60	90	-60	-110	90	-110	-250	80	-250
VOC emissions	$/ton	210	1,090	1,980	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
CO emissions	$/ton	20	90	160	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
NOX emissions	$/ton	1,710	6,350	10,740	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
PM10 emissions	$/ton	11,430	20,260	29,100	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
PM2.5 emissions	$/ton	21,630	173,860	326,100	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
SOX emissions	$/ton	6,980	31,490	56,000	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
GHGs	$/ton CO2-equevalent	1.5	14	70	10	100	500	10	90	470	10	90	440	10	90	430	10	80	410
Energy Security	$/gallon	0.02	0.37	0.63	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80
Congestion	$/mile	0.02	0.035	0.09	100	100	100	90	90	90	90	90	90	90	90	90	80	80	80

*relative to the price of other goods and services

Energy Security Benefit Relative to CV

Table D.9: Sensitivity of Energy Security Benefit Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	65%	-60%	53%	-48%	46%	-42%	42%	-38%	33%	-31%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	3%	-3%	4%	-4%	4%	-4%	0%	0%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-3%	7%	-4%	7%	-4%	6%	0%	0%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	-2%	0%	-1%	0%	-1%	0%	-2%	0%	-1%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%
Discount Rate	-	3%	7%	10	26%	-14%	26%	-14%	27%	-14%	27%	-14%	27%	-14%
VMT Elasticity	-	-0.05	-0.15	-0.25	11%	-12%	9%	-10%	8%	-9%	6%	-8%	0%	-1%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	26%	-17%	21%	-17%	18%	-18%	17%	-23%	24%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	-95%	69%	-94%	70%	-95%	70%	-95%	70%	-95%	70%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.10: Energy Security Benefit Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	1,070	650	260	1,330	870	450	1,470	1,010	590	1,590	1,120	690	1,960	1,470	1,010
Price of gasoline	$/gallon	1.5	2.5	4.5	650	650	650	900	870	840	1,050	1,010	970	1,160	1,120	1,080	1,470	1,470	1,470
Price of electricity	$/kWh	0.06	0.1	0.25	650	650	650	840	870	930	970	1,010	1,080	1,080	1,120	1,190	1,470	1,470	1,470
Change in Price of Gasoline*	-	0.99	1	1.01	650	650	640	870	870	860	1,010	1,010	1,000	1,120	1,120	1,100	1,470	1,470	1,450
Change in Price of Electricity*	-	0.99	1	1.01	650	650	650	870	870	870	1,010	1,010	1,010	1,110	1,120	1,120	1,470	1,470	1,470
Discount Rate	-	3%	7%	10%	820	650	560	1,100	870	750	1,280	1,010	870	1,420	1,120	960	1,860	1,470	1,270
VMT Elasticity	-	-0.05	-0.15	-0.25	720	650	570	950	870	780	1,090	1,010	920	1,190	1,120	1,030	1,470	1,470	1,460
VMT distribution	-	Low VMT	Medium VMT	VMT High	500	650	820	720	870	1,050	840	1,010	1,190	920	1,120	1,310	1,130	1,470	1,830
Nuclear	-	-	-	-	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
NGCC	-	-	-	-	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
COAL	-	-	-	-	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
VOC emissions	$/ton	210	1,090	1,980	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
CO emissions	$/ton	20	90	160	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
NOX emissions	$/ton	1,710	6,350	10,740	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
PM10 emissions	$/ton	11,430	20,260	29,100	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
PM2.5 emissions	$/ton	21,630	173,860	326,100	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
SOX emissions	$/ton	6,980	31,490	56,000	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
GHGs	$/ton CO2-equevalent	1.5	14	70	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470
Energy Security	$/gallon	0.02	0.37	0.63	30	650	1,100	50	870	1,480	50	1,010	1,720	60	1,120	1,900	80	1,470	2,500
Congestion	$/mile	0.02	0.035	0.09	650	650	650	870	870	870	1,010	1,010	1,010	1,120	1,120	1,120	1,470	1,470	1,470

*relative to the price of other goods and services

Congestion Cost Relative to CV

Table D.11: Sensitivity of Congestion Cost Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	65%	-59%	27%	-34%	26%	-31%	25%	-29%	23%	-29%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	-27%	24%	-31%	31%	-33%	35%	-39%	48%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	21%	-52%	28%	-59%	31%	-61%	41%	-68%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	-2%	2%	-3%	1%	-1%	1%	-1%	0%	0%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	2%	-3%	3%	-3%	3%	-4%	2%	-6%
Discount Rate	-	3%	7%	10	28%	-13%	27%	-13%	28%	-13%	28%	-14%	26%	-14%
VMT Elasticity	-	-0.05	-0.15	-0.25	-67%	67%	-68%	74%	-68%	76%	-68%	76%	-69%	79%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-22%	28%	-19%	26%	-19%	25%	-21%	24%	-24%	26%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	15%	15%	15%	15%	15%	15%	15%	15%	14%	14%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	-43%	157%	-42%	158%	-43%	159%	-43%	158%	-44%	156%

*relative to the price of other goods and services

Table D.12: Congestion Cost Relative to CV (PV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-890	-540	-220	-790	-620	-410	-860	-680	-470	-900	-720	-510	-980	-800	-570
Price of gasoline	$/gallon	1.5	2.5	4.5	-540	-540	-540	-450	-620	-770	-470	-680	-890	-480	-720	-970	-490	-800	-1,180
Price of electricity	$/kWh	0.06	0.1	0.25	-540	-540	-540	-750	-620	-300	-870	-680	-280	-940	-720	-280	-1,130	-800	-260
Change in Price of Gasoline*	-	0.99	1	1.01	-540	-540	-530	-630	-620	-600	-690	-680	-670	-730	-720	-710	-800	-800	-800
Change in Price of Electricity*	-	0.99	1	1.01	-540	-540	-540	-630	-620	-600	-700	-680	-660	-740	-720	-690	-820	-800	-750
Discount	-	3%	7%	10%	-690	-540	-470	-790	-620	-540	-870	-680	-590	-	-720	-620	-	-800	-690
VMT Elasticity	-	-0.05	-0.15	-0.25	-180	-540	-900	-200	-620	-1,080	-220	-680	-1,200	-230	-720	-1,270	-250	-800	-1,430
VMT distribution	-	Low VMT	Medium VMT	VMT High	-420	-540	-690	-500	-620	-780	-550	-680	-850	-570	-720	-890	-610	-800	-1,010
Nuclear	-	-	-	-	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
NGCC	-	-	-	-	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
COAL	-	-	-	-	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
VOC	$/ton	210	1,090	1,980	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
CO emissions	$/ton	20	90	160	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
NOX	$/ton	1,710	6,350	10,740	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
PM10	$/ton	11,430	20,260	29,100	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
PM2.5	$/ton	21,630	173,860	326,100	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
SOX	$/ton	6,980	31,490	56,000	-540	-540	-540	-620	-620	-620	-680	-680	-680	-	-720	-720	-800	-800	-800
GHGs	$/ton CO2-equevalent	1.5	14	70	-620	-540	-620	-710	-620	-710	-780	-680	-780	-830	-720	-830	-910	-800	-910
Energy Security	$/gallon	0.02	0.37	0.63	-540	-540	-540	-620	-620	-620	-680	-680	-680	-720	-720	-720	-800	-800	-800
Congestion	$/mile	0.02	0.035	0.09	-310	-540	-	-360	-620	-	-390	-680	-1,760	-	-720	-1,860	-450	-800	-2,050

*relative to the price of other goods and services

External Benefits Relative to CV

Table D.13: Sensitivity of the Net External Benefits Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-5%	-23%	84%	-61%	65%	-51%	55%	-43%	38%	-28%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	81%	-68%	81%	-81%	81%	-88%	59%	-77%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-61%	152%	-73%	151%	-76%	148%	-66%	105%
Change in Price of Gasoline*	-	0.99	1	1.01	-5%	-5%	0%	3%	-3%	-3%	0%	-5%	2%	-3%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-3%	10%	-8%	8%	-7%	10%	-5%	8%
Discount Rate	-	3%	7%	10	27%	-14%	29%	-13%	27%	-16%	29%	-14%	30%	-14%
VMT Elasticity	-	-0.05	-0.15	-0.25	236%	-241%	197%	-213%	178%	-200%	164%	-186%	108%	-125%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	23%	-16%	16%	-16%	8%	-17%	10%	-23%	23%
Nuclear	-	-	-	-	0%	0%	84%	84%	116%	116%	131%	131%	150%	150%
NGCC	-	-	-	-	0%	0%	39%	39%	51%	51%	57%	57%	66%	66%
COAL	-	-	-	-	0%	0%	-58%	-58%	-81%	-81%	-90%	-90%	-103%	-103%
VOC emissions	$/ton	210	1,090	1,980	-5%	0%	0%	3%	-3%	0%	-2%	2%	-3%	2%
CO emissions	$/ton	20	90	160	0%	-5%	0%	0%	-3%	0%	-2%	0%	-3%	2%
NOX emissions	$/ton	1,710	6,350	10,740	-5%	0%	-3%	3%	-3%	3%	-5%	2%	-3%	2%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	-2%	0%	-2%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	5%	-5%	-3%	6%	-8%	8%	-12%	10%	-13%	13%
SOX emissions	$/ton	6,980	31,490	56,000	-9%	5%	16%	-16%	24%	-24%	29%	-29%	33%	-34%
GHGs	$/ton CO2-equevalent	1.5	14	70	-77%	145%	-55%	94%	-49%	68%	-43%	57%	-30%	33%
Energy Security	$/gallon	0.02	0.37	0.63	-277%	205%	-265%	197%	-259%	192%	-252%	186%	-217%	161%
Congestion	$/mile	0.02	0.035	0.09	105%	-386%	87%	-316%	78%	-292%	74%	-271%	53%	-195%

*relative to the price of other goods and services

Table D.14: Net External Benefits Relative to CV (NPV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	210	220	170	570	310	120	610	370	180	650	420	240	880	640	460
Price of gasoline	$/gallon	1.5	2.5	4.5	220	220	220	560	310	100	670	370	70	760	420	50	1,020	640	150
Price of electricity	$/kWh	0.06	0.1	0.25	220	220	220	120	310	780	100	370	930	100	420	1,040	220	640	1,310
Change in Price of Gasoline*	-	0.99	1	1.01	210	220	210	310	310	320	360	370	360	420	420	400	650	640	620
Change in Price of Electricity*	-	0.99	1	1.01	220	220	220	300	310	340	340	370	400	390	420	460	610	640	690
Discount Rate	-	3%	7%	10%	280	220	190	400	310	270	470	370	310	540	420	360	830	640	550
VMT Elasticity	-	-0.05	-0.15	-0.25	740	220	-310	920	310	-350	1,030	370	-370	1,110	420	-360	1,330	640	-160
VMT distribution	-	Low VMT	Medium VMT	VMT High	170	220	270	260	310	360	310	370	400	350	420	460	490	640	790
Nuclear	-	-	-	-	220	220	220	570	310	570	800	370	800	970	420	970	1,600	640	1,600
NGCC	-	-	-	-	220	220	220	430	310	430	560	370	560	660	420	660	1,060	640	1,060
COAL	-	-	-	-	220	220	220	130	310	130	70	370	70	40	420	40	-20	640	-20
VOC emissions	$/ton	210	1,090	1,980	210	220	220	310	310	320	360	370	370	410	420	430	620	640	650
CO emissions	$/ton	20	90	160	220	220	210	310	310	310	360	370	370	410	420	420	620	640	650
NOX emissions	$/ton	1,710	6,350	10,740	210	220	220	300	310	320	360	370	380	400	420	430	620	640	650
PM10 emissions	$/ton	11,430	20,260	29,100	220	220	220	310	310	310	370	370	370	410	420	420	630	640	640
PM2.5 emissions	$/ton	21,630	173,860	326,100	230	220	210	300	310	330	340	370	400	370	420	460	560	640	720
SOX emissions	$/ton	6,980	31,490	56,000	200	220	230	360	310	260	460	370	280	540	420	300	850	640	420
GHGs	$/ton CO2-equevalent	1.5	14	70	50	220	540	140	310	600	190	370	620	240	420	660	450	640	850
Energy Security	$/gallon	0.02	0.37	0.63	-390	220	670	-510	310	920	-590	370	1,080	-640	420	1,200	-750	640	1,670
Congestion	$/mile	0.02	0.035	0.09	450	220	-630	580	310	-670	660	370	-710	730	420	-720	980	640	-610

*relative to the price of other goods and services

Net Societal Benefit Relative to CV

Table D.15: Sensitivity of the Net Societal Benefit Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	65%	-60%	53%	-47%	50%	-45%	48%	-43%	55%	-50%
Price of gasoline	$/gallon	1.5	2.5	4.5	-39%	77%	-45%	94%	-46%	95%	-46%	96%	-55%	116%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	7%	-30%	8%	-34%	8%	-36%	11%	-47%
Change in Price of Gasoline*	-	0.99	1	1.01	-3%	6%	-3%	7%	-4%	8%	-4%	8%	-4%	9%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	1%	-2%	1%	-2%	1%	-2%	1%	-3%
Discount Rate	-	3%	7%	10	27%	-14%	27%	-14%	27%	-14%	27%	-14%	33%	-17%
VMT Elasticity	-	-0.05	-0.15	-0.25	6%	-6%	4%	-5%	4%	-5%	4%	-5%	3%	-4%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	27%	-21%	26%	-21%	25%	-21%	25%	-28%	32%
Nuclear	-	-	-	-	0%	0%	3%	3%	5%	5%	7%	7%	13%	13%
NGCC	-	-	-	-	0%	0%	2%	2%	2%	2%	3%	3%	6%	6%
COAL	-	-	-	-	0%	0%	-2%	-2%	-4%	-4%	-5%	-5%	-9%	-9%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	-1%	0%	-1%	1%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	1%	-1%	1%	-1%	1%	-1%	3%	-3%
GHGs	$/ton CO2-equevalent	1.5	14	70	-3%	6%	-2%	4%	-2%	3%	-2%	3%	-3%	3%
Energy Security	$/gallon	0.02	0.37	0.63	-11%	8%	-11%	8%	-12%	9%	-13%	9%	-19%	14%
Congestion	$/mile	0.02	0.035	0.09	4%	-15%	4%	-13%	4%	-14%	4%	-14%	5%	-17%

*relative to the price of other goods and services

Table D.16: Net Societal Benefit Relative to CV (NPV, $ 2009)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	9,270	5,610	2,270	11,520	7,540	3,990	11,960	7,970	4,410	12,220	8,230	4,660	11,360	7,330	3,700
Price of gasoline	$/gallon	1.5	2.5	4.5	3,450	5,610	9,920	4,160	7,540	14,590	4,340	7,970	15,570	4,470	8,230	16,120	3,300	7,330	15,850
Price of electricity	$/kWh	0.06	0.1	0.25	5,610	5,610	5,610	8,090	7,540	5,270	8,610	7,970	5,250	8,910	8,230	5,270	8,130	7,330	3,900
Change in Price of Gasoline*	-	0.99	1	1.01	5,450	5,610	5,930	7,280	7,540	8,100	7,680	7,970	8,580	7,930	8,230	8,860	7,010	7,330	8,010
Change in Price of Electricity*	-	0.99	1	1.01	5,610	5,610	5,610	7,600	7,540	7,420	8,030	7,970	7,820	8,300	8,230	8,070	7,410	7,330	7,140
Discount	-	3%	7%	10%	7,130	5,610	4,840	9,590	7,540	6,510	10,140	7,970	6,870	10,470	8,230	7,100	9,740	7,330	6,110
VMT Elasticity	-	-0.05	-0.15	-0.25	5,960	5,610	5,260	7,870	7,540	7,160	8,320	7,970	7,570	8,570	8,230	7,820	7,570	7,330	7,010
VMT distribution	-	Low VMT	Medium VMT	VMT High	4,330	5,610	7,140	5,950	7,540	9,470	6,300	7,970	9,970	6,470	8,230	10,270	5,310	7,330	9,690
Nuclear	-	-	-	-	5,610	5,610	5,610	7,800	7,540	7,800	8,400	7,970	8,400	8,780	8,230	8,780	8,290	7,330	8,290
NGCC	-	-	-	-	5,610	5,610	5,610	7,660	7,540	7,660	8,160	7,970	8,160	8,470	8,230	8,470	7,750	7,330	7,750
COAL	-	-	-	-	5,610	5,610	5,610	7,360	7,540	7,360	7,670	7,970	7,670	7,850	8,230	7,850	6,670	7,330	6,670
VOC	$/ton	210	1,090	1,980	5,600	5,610	5,610	7,540	7,540	7,550	7,960	7,970	7,970	8,220	8,230	8,240	7,310	7,330	7,340
CO emissions	$/ton	20	90	160	5,610	5,610	5,600	7,540	7,540	7,540	7,960	7,970	7,970	8,220	8,230	8,230	7,310	7,330	7,340
NOX	$/ton	1,710	6,350	10,740	5,600	5,610	5,610	7,530	7,540	7,550	7,960	7,970	7,980	8,210	8,230	8,240	7,310	7,330	7,340
PM10	$/ton	11,430	20,260	29,100	5,610	5,610	5,610	7,540	7,540	7,540	7,970	7,970	7,970	8,220	8,230	8,230	7,320	7,330	7,330
PM2.5	$/ton	21,630	173,860	326,100	5,620	5,610	5,600	7,530	7,540	7,560	7,940	7,970	8,000	8,180	8,230	8,270	7,250	7,330	7,410
SOX	$/ton	6,980	31,490	56,000	5,590	5,610	5,620	7,590	7,540	7,490	8,060	7,970	7,880	8,350	8,230	8,110	7,540	7,330	7,110
GHGs	$/ton CO2-equevalent	1.5	14	70	5,440	5,610	5,930	7,370	7,540	7,830	7,790	7,970	8,220	8,050	8,230	8,470	7,140	7,330	7,540
Energy Security	$/gallon	0.02	0.37	0.63	5,000	5,610	6,060	6,720	7,540	8,150	7,010	7,970	8,680	7,170	8,230	9,010	5,940	7,330	8,360
Congestion	$/mile	0.02	0.035	0.09	5,840	5,610	4,760	7,810	7,540	6,560	8,260	7,970	6,890	8,540	8,230	7,090	7,670	7,330	6,080

*relative to the price of other goods and services

VOC Reduction Relative to CV

Table D.17: Sensitivity of VOC Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-43%	39%	-9%	11%	-6%	7%	-5%	5%	0%	0%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	8%	-7%	7%	-7%	6%	-6%	0%	0%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-7%	16%	-6%	13%	-6%	11%	0%	0%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	0%	-1%	0%	-1%	0%	0%	0%	0%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-1%	1%	-1%	1%	-1%	1%	0%	0%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	43%	-43%	21%	-23%	16%	-17%	12%	-14%	0%	0%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	15%	-12%	15%	-14%	12%	-14%	0%	-3%
Nuclear	-	-	-	-	0%	0%	1%	1%	1%	1%	1%	1%	1%	1%
NGCC	-	-	-	-	0%	0%	-2%	-2%	-2%	-2%	-2%	-2%	-3%	-3%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.18: VOC Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-10%	-18%	-24%	-36%	-39%	-44%	-50%	-53%	-57%	-61%	-64%	-68%	-99%	-99%	-99%
Price of gasoline	$/gallon	1.5	2.5	4.5	-18%	-18%	-18%	-43%	-39%	-37%	-57%	-53%	-50%	-68%	-64%	-60%	-99%	-99%	-99%
Price of electricity	$/kWh	0.06	0.1	0.25	-18%	-18%	-18%	-37%	-39%	-46%	-50%	-53%	-61%	-60%	-64%	-71%	-99%	-99%	-99%
Change in Price of Gasoline*	-	0.99	1	1.01	-18%	-18%	-18%	-40%	-39%	-39%	-54%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
Change in Price of Electricity*	-	0.99	1	1.01	-18%	-18%	-18%	-39%	-39%	-40%	-53%	-53%	-54%	-64%	-64%	-65%	-99%	-99%	-99%
Discount Rate	-	3%	7%	10%	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
VMT Elasticity	-	-0.05	-0.15	-0.25	-25%	-18%	-10%	-48%	-39%	-30%	-62%	-53%	-44%	-72%	-64%	-55%	-99%	-99%	-98%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-18%	-18%	-18%	-45%	-39%	-35%	-61%	-53%	-46%	-72%	-64%	-55%	-99%	-99%	-95%
Nuclear	-	-	-	-	-18%	-18%	-18%	-40%	-39%	-40%	-54%	-53%	-54%	-65%	-64%	-65%	-	-99%	-
NGCC	-	-	-	-	-18%	-18%	-18%	-39%	-39%	-39%	-52%	-53%	-52%	-63%	-64%	-63%	-96%	-99%	-96%
COAL	-	-	-	-	-18%	-18%	-18%	-40%	-39%	-40%	-54%	-53%	-54%	-64%	-64%	-64%	-99%	-99%	-99%
VOC emissions	$/ton	210	1,090	1,980	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
CO emissions	$/ton	20	90	160	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
NOX emissions	$/ton	1,710	6,350	10,740	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
PM10 emissions	$/ton	11,43	20,260	29,100	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
PM2.5 emissions	$/ton	21,63	173,860	326,10	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
SOX emissions	$/ton	6,980	31,490	56,000	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
GHGs	$/ton CO2-equevalent	1.5	14	70	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
Energy Security	$/gallon	0.02	0.37	0.63	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%
Congestion	$/mile	0.02	0.035	0.09	-18%	-18%	-18%	-39%	-39%	-39%	-53%	-53%	-53%	-64%	-64%	-64%	-99%	-99%	-99%

*relative to the price of other goods and services

CO Reduction Relative to CV

Table D.19: Sensitivity of CO Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	66%	-61%	-32%	39%	-13%	16%	-8%	10%	0%	0%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	31%	-27%	16%	-15%	11%	-11%	0%	0%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-24%	59%	-13%	29%	-10%	20%	0%	0%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	2%	-3%	1%	-1%	0%	-1%	0%	0%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-2%	5%	-1%	3%	-1%	2%	0%	0%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	-68%	68%	77%	-84%	34%	-37%	22%	-25%	0%	-1%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	55%	-44%	32%	-30%	22%	-26%	0%	-5%
Nuclear	-	-	-	-	0%	0%	2%	2%	1%	1%	1%	1%	1%	1%
NGCC	-	-	-	-	0%	0%	-3%	-3%	-2%	-2%	-2%	-2%	-1%	-1%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.20: CO Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	26%	16%	6%	-10%	-15%	-21%	-30%	-35%	-40%	-46%	-50%	-55%	-99%	-99%	-99%
Price of gasoline	$/gallon	1.5	2.5	4.5	16%	16%	16%	-20%	-15%	-11%	-40%	-35%	-30%	-56%	-50%	-44%	-99%	-99%	-99%
Price of electricity	$/kWh	0.06	0.1	0.25	16%	16%	16%	-12%	-15%	-24%	-30%	-35%	-45%	-45%	-50%	-60%	-99%	-99%	-99%
Change in Price of Gasoline*	-	0.99	1	1.01	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-34%	-50%	-50%	-50%	-99%	-99%	-99%
Change in Price of Electricity*	-	0.99	1	1.01	16%	16%	16%	-15%	-15%	-16%	-34%	-35%	-36%	-50%	-50%	-51%	-99%	-99%	-99%
Discount Rate	-	3%	7%	10%	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
VMT Elasticity	-	-0.05	-0.15	-0.25	5%	16%	27%	-27%	-15%	-2%	-47%	-35%	-22%	-61%	-50%	-38%	-99%	-99%	-99%
VMT distribution	-	Low VMT	Medium VMT	VMT High	16%	16%	16%	-24%	-15%	-9%	-46%	-35%	-25%	-61%	-50%	-37%	-99%	-99%	-94%
Nuclear	-	-	-	-	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-100%	-99%	-100%
NGCC	-	-	-	-	16%	16%	16%	-15%	-15%	-15%	-34%	-35%	-34%	-49%	-50%	-49%	-98%	-99%	-98%
COAL	-	-	-	-	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
VOC emissions	$/ton	210	1,090	1,980	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
CO emissions	$/ton	20	90	160	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
NOX emissions	$/ton	1,710	6,350	10,740	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
PM10 emissions	$/ton	11,430	20,260	29,100	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
PM2.5 emissions	$/ton	21,630	173,860	326,100	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
SOX emissions	$/ton	6,980	31,490	56,000	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
GHGs	$/ton CO2-equevalent	1.5	14	70	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
Energy Security	$/gallon	0.02	0.37	0.63	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%
Congestion	$/mile	0.02	0.035	0.09	16%	16%	16%	-15%	-15%	-15%	-35%	-35%	-35%	-50%	-50%	-50%	-99%	-99%	-99%

*relative to the price of other goods and services

NOX Reduction Relative to CV

Table D.21: Sensitivity of NOx Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-91%	84%	-23%	29%	-18%	22%	-15%	18%	-7%	9%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	23%	-20%	22%	-21%	21%	-21%	12%	-15%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-18%	44%	-19%	41%	-19%	37%	-13%	20%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	1%	-3%	1%	-3%	1%	-3%	1%	-2%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-2%	3%	-2%	3%	-2%	3%	-1%	2%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	93%	-93%	57%	-62%	48%	-52%	41%	-46%	21%	-25%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	12%	-10%	13%	-13%	11%	-13%	0%	-3%
Nuclear	-	-	-	-	0%	0%	98%	98%	125%	125%	138%	138%	157%	157%
NGCC	-	-	-	-	0%	0%	-13%	-13%	-16%	-16%	-18%	-18%	-20%	-20%
COAL	-	-	-	-	0%	0%	-43%	-43%	-55%	-55%	-60%	-60%	-68%	-68%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.22: NOx Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-1%	-9%	-17%	-13%	-17%	-22%	-18%	-22%	-26%	- 22%	-25%	-30%	-36%	-39%	-42%
Price of gasoline	$/gallon	1.5	2.5	4.5	-9%	-9%	-9%	-21%	-17%	-14%	-26%	-22%	-17%	- 31%	-25%	-20%	-43%	-39%	-33%
Price of electricity	$/kWh	0.06	0.1	0.25	-9%	-9%	-9%	-14%	-17%	-24%	-18%	-22%	-30%	- 21%	-25%	-35%	-34%	-39%	-47%
Change in Price of Gasoline*	-	0.99	1	1.01	-9%	-9%	-9%	-17%	-17%	-16%	-22%	-22%	-21%	- 26%	-25%	-25%	-39%	-39%	-38%
Change in Price of Electricity*	-	0.99	1	1.01	-9%	-9%	-9%	-17%	-17%	-17%	-21%	-22%	-22%	- 25%	-25%	-26%	-38%	-39%	-39%
Discount Rate	-	3%	7%	10%	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
VMT Elasticity	-	-0.05	-0.15	-0.25	- 17%	-9%	-1%	-26%	-17%	-6%	-32%	-22%	-10%	- 36%	-25%	-14%	-47%	-39%	-29%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-9%	-9%	-9%	-19%	-17%	-15%	-24%	-22%	-19%	- 28%	-25%	-22%	-39%	-39%	-37%
Nuclear	-	-	-	-	-9%	-9%	-9%	-33%	-17%	-33%	-49%	-22%	-49%	-	-25%	-61%	-99%	-39%	-99%
NGCC	-	-	-	-	-9%	-9%	-9%	-15%	-17%	-15%	-18%	-22%	-18%	-	-25%	-21%	-31%	-39%	-31%
COAL	-	-	-	-	-9%	-9%	-9%	-10%	-17%	-10%	-10%	-22%	-10%	-	-25%	-10%	-12%	-39%	-12%
VOC emissions	$/ton	210	1,090	1,980	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
CO emissions	$/ton	20	90	160	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
NOX emissions	$/ton	1,710	6,350	10,740	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
PM10 emissions	$/ton	11,430	20,260	29,100	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
PM2.5	$/ton	21,630	173,860	326,100	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
SOX emissions	$/ton	6,980	31,490	56,000	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%
GHGs	$/ton CO2-equevalent	1.5	14	70	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	- 25%	-25%	-25%	-39%	-39%	-39%
Energy Security	$/gallon	0.02	0.37	0.63	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	- 25%	-25%	-25%	-39%	-39%	-39%
Congestion	$/mile	0.02	0.035	0.09	-9%	-9%	-9%	-17%	-17%	-17%	-22%	-22%	-22%	-	-25%	-25%	-39%	-39%	-39%

*relative to the price of other goods and services

PM10 Reduction Relative to CV

Table D.23: Sensitivity of PM10 Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	157%	-144%	-458%	557%	-86%	104%	-51%	61%	-16%	20%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	441%	-387%	105%	-101%	70%	-72%	27%	-34%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-344%	848%	-89%	194%	-63%	125%	-29%	47%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	32%	-61%	8%	-15%	5%	-10%	2%	-5%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-34%	72%	-9%	18%	-6%	12%	-3%	5%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	-160%	160%	1114%	-1213%	226%	-249%	139%	-155%	49%	-57%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	186%	-161%	49%	-48%	30%	-36%	0%	-6%
Nuclear	-	-	-	-	10%	10%	350%	350%	116%	116%	93%	93%	69%	69%
NGCC	-	-	-	-	0%	0%	37%	37%	12%	12%	9%	9%	7%	7%
COAL	-	-	-	-	0%	0%	-267%	-267%	-83%	-83%	-65%	-65%	-46%	-46%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.24: PM10 Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Bas	High	Low	Bas	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	16%	6%	-3%	4%	-1%	-7%	-1%	-5%	-11%	-4%	-9%	-14%	-18%	-21%	-26%
Price of gasoline	$/gallon	1.5	2.5	4.5	6%	6%	6%	-5%	-1%	3%	-11%	-5%	0%	-15%	-9%	-3%	-27%	-21%	-14%
Price of electricity	$/kWh	0.06	0.1	0.25	6%	6%	6%	2%	-1%	-10%	-1%	-5%	-16%	-3%	-9%	-20%	-15%	-21%	-31%
Change in Price of Gasoline*	-	0.99	1	1.01	6%	6%	6%	-1%	-1%	0%	-6%	-5%	-5%	-9%	-9%	-8%	-22%	-21%	-20%
Change in Price of Electricity*	-	0.99	1	1.01	6%	6%	6%	-1%	-1%	-2%	-5%	-5%	-6%	-8%	-9%	-10%	-21%	-21%	-22%
Discount Rate	-	3%	7%	10%	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
VMT Elasticity	-	-0.05	-0.15	-0.25	-4%	6%	16%	-12%	-1%	11%	-17%	-5%	8%	-21%	-9%	5%	-32%	-21%	-9%
VMT distribution	-	Low VMT	Medium VMT	VMT High	6%	6%	6%	-3%	-1%	1%	-8%	-5%	-3%	-12%	-9%	-6%	-21%	-21%	-20%
Nuclear	-	-	-	-	7%	6%	7%	-5%	-1%	-5%	-12%	-5%	-12%	-17%	-9%	-17%	-36%	-21%	-36%
NGCC	-	-	-	-	6%	6%	6%	-1%	-1%	-1%	-6%	-5%	-6%	-10%	-9%	-10%	-23%	-21%	-23%
COAL	-	-	-	-	6%	6%	6%	2%	-1%	2%	-1%	-5%	-1%	-3%	-9%	-3%	-11%	-21%	-11%
VOC emissions	$/ton	210	1,090	1,980	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
CO emissions	$/ton	20	90	160	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
NOX emissions	$/ton	1,710	6,350	10,740	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
PM10 emissions	$/ton	11,430	20,260	29,100	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
PM2.5 emissions	$/ton	21,630	173,860	326,100	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
SOX emissions	$/ton	6,980	31,490	56,000	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
GHGs	$/ton CO2-equevalent	1.5	14	70	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
Energy Security	$/gallon	0.02	0.37	0.63	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%
Congestion	$/mile	0.02	0.035	0.09	6%	6%	6%	-1%	-1%	-1%	-5%	-5%	-5%	-9%	-9%	-9%	-21%	-21%	-21%

*relative to the price of other goods and services

PM2.5 Reduction Relative to CV

Table D.25: Sensitivity of PM2.5 Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	185%	-170%	-64%	78%	-30%	37%	-21%	25%	-6%	8%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	62%	-54%	37%	-36%	28%	-29%	11%	-13%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-48%	118%	-31%	68%	-26%	51%	-11%	18%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	4%	-8%	3%	-5%	2%	-4%	1%	-2%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-5%	10%	-3%	6%	-2%	5%	-1%	2%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	-189%	189%	155%	-169%	79%	-88%	56%	-63%	19%	-22%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	46%	-38%	30%	-29%	22%	-25%	0%	-5%
Nuclear	-	-	-	-	0%	0%	69%	69%	54%	54%	50%	50%	44%	44%
NGCC	-	-	-	-	0%	0%	-38%	-38%	-30%	-30%	-27%	-27%	-24%	-24%
COAL	-	-	-	-	0%	0%	-26%	-26%	-20%	-20%	-19%	-19%	-16%	-16%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.26: PM2.5 Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	15%	5%	-4%	-3%	-7%	-13%	-10%	-15%	-20%	-16%	-21%	-26%	-38%	-41%	-44%
Price of gasoline	$/gallon	1.5	2.5	4.5	5%	5%	5%	-11%	-7%	-3%	-20%	-15%	-9%	-27%	-21%	-15%	-45%	-41%	-36%
Price of electricity	$/kWh	0.06	0.1	0.25	5%	5%	5%	-4%	-7%	-16%	-10%	-15%	-25%	-15%	-21%	-31%	-36%	-41%	-49%
Change in Price of Gasoline*	-	0.99	1	1.01	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-14%	-21%	-21%	-20%	-41%	-41%	-40%
Change in Price of Electricity*	-	0.99	1	1.01	5%	5%	5%	-7%	-7%	-8%	-14%	-15%	-16%	-20%	-21%	-22%	-41%	-41%	-42%
Discount Rate	-	3%	7%	10%	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
VMT Elasticity	-	-0.05	-0.15	-0.25	-5%	5%	15%	-18%	-7%	5%	-26%	-15%	-2%	-32%	-21%	-8%	-49%	-41%	-32%
VMT distribution	-	Low VMT	Medium VMT	VMT High	5%	5%	5%	-10%	-7%	-4%	-19%	-15%	-10%	-25%	-21%	-16%	-41%	-41%	-39%
Nuclear	-	-	-	-	5%	5%	5%	-12%	-7%	-12%	-23%	-15%	-23%	-31%	-21%	-31%	-59%	-41%	-59%
NGCC	-	-	-	-	5%	5%	5%	-4%	-7%	-4%	-10%	-15%	-10%	-15%	-21%	-15%	-31%	-41%	-31%
COAL	-	-	-	-	5%	5%	5%	-5%	-7%	-5%	-12%	-15%	-12%	-17%	-21%	-17%	-34%	-41%	-34%
VOC emissions	$/ton	210	1,090	1,980	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
CO emissions	$/ton	20	90	160	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
NOX emissions	$/ton	1,710	6,350	10,740	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
PM10 emissions	$/ton	11,430	20,260	29,100	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
PM2.5 emissions	$/ton	21,630	173,860	326,100	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
SOX emissions	$/ton	6,980	31,490	56,000	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
GHGs	$/ton CO2-equevalent	1.5	14	70	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
Energy Security	$/gallon	0.02	0.37	0.63	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%
Congestion	$/mile	0.02	0.035	0.09	5%	5%	5%	-7%	-7%	-7%	-15%	-15%	-15%	-21%	-21%	-21%	-41%	-41%	-41%

*relative to the price of other goods and services

SOX Reduction Relative to CV

Table D.27: Sensitivity of SOx Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-44%	41%	7%	-9%	5%	-6%	4%	-5%	6%	-7%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	-7%	6%	-6%	6%	-6%	6%	-10%	13%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	5%	-14%	5%	-11%	6%	-12%	11%	-18%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	-1%	2%	-1%	2%	-1%	2%	-1%	2%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	1%	-1%	0%	-1%	0%	-1%	1%	-2%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	45%	-45%	-18%	19%	-13%	14%	-13%	13%	-18%	21%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	35%	-26%	25%	-22%	18%	-21%	0%	-4%
Nuclear	-	-	-	-	0%	0%	-161%	-161%	-145%	-145%	-141%	-141%	-135%	-135%
NGCC	-	-	-	-	0%	0%	-162%	-162%	-146%	-146%	-141%	-141%	-136%	-136%
COAL	-	-	-	-	0%	0%	123%	123%	111%	111%	108%	108%	103%	103%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.28: SOx Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-10%	-17%	-24%	67%	62%	57%	119%	113%	107%	159%	152%	144%	289%	272%	252%
Price of gasoline	$/gallon	1.5	2.5	4.5	-17%	-17%	-17%	58%	62%	66%	107%	113%	120%	143%	152%	161%	245%	272%	306%
Price of electricity	$/kWh	0.06	0.1	0.25	-17%	-17%	-17%	66%	62%	54%	119%	113%	100%	160%	152%	134%	302%	272%	224%
Change in Price of Gasoline*	-	0.99	1	1.01	-17%	-17%	-17%	61%	62%	64%	112%	113%	115%	150%	152%	154%	270%	272%	277%
Change in Price of Electricity*	-	0.99	1	1.01	-17%	-17%	-17%	62%	62%	62%	114%	113%	112%	153%	152%	150%	275%	272%	268%
Discount Rate	-	3%	7%	10%	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
VMT Elasticity	-	-0.05	-0.15	-0.25	-25%	-17%	-9%	51%	62%	74%	98%	113%	129%	132%	152%	172%	223%	272%	328%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-17%	-17%	-17%	84%	62%	46%	142%	113%	88%	180%	152%	120%	272%	272%	261%
Nuclear	-	-	-	-	-17%	-17%	-17%	-38%	62%	-38%	-51%	113%	-51%	-62%	152%	-62%	-95%	272%	-95%
NGCC	-	-	-	-	-17%	-17%	-17%	-39%	62%	-39%	-52%	113%	-52%	-63%	152%	-63%	-97%	272%	-97%
COAL	-	-	-	-	-17%	-17%	-17%	139%	62%	139%	239%	113%	239%	315%	152%	315%	553%	272%	553%
VOC emissions	$/ton	210	1,090	1,980	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
CO emissions	$/ton	20	90	160	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
NOX emissions	$/ton	1,710	6,350	10,740	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
PM10 emissions	$/ton	11,430	20,260	29,100	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
PM2.5 emissions	$/ton	21,630	173,860	326,100	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
SOX emissions	$/ton	6,980	31,490	56,000	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
GHGs	$/ton CO2-equevalent	1.5	14	70	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
Energy Security	$/gallon	0.02	0.37	0.63	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%
Congestion	$/mile	0.02	0.035	0.09	-17%	-17%	-17%	62%	62%	62%	113%	113%	113%	152%	152%	152%	272%	272%	272%

*relative to the price of other goods and services

GHGs Reduction Relative to CV

Table D.29: Sensitivity of GHG Emissions Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	-45%	41%	-23%	28%	-24%	29%	-25%	30%	-25%	30%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	22%	-19%	29%	-28%	34%	-35%	40%	-51%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-17%	43%	-25%	55%	-31%	62%	-44%	70%
Change in Price of Gasoline*	-	0.99	1	1.01	0%	0%	2%	-3%	2%	-5%	3%	-6%	4%	-7%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	-2%	4%	-2%	5%	-3%	6%	-4%	7%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	46%	-46%	56%	-61%	64%	-70%	68%	-76%	73%	-84%
VMT distribution	-	Low VMT	Medium VMT	VMT High	0%	0%	-1%	0%	-1%	0%	-1%	0%	0%	0%
Nuclear	-	-	-	-	0%	0%	141%	141%	240%	240%	317%	317%	540%	540%
NGCC	-	-	-	-	0%	0%	22%	22%	37%	37%	49%	49%	83%	83%
COAL	-	-	-	-	0%	0%	-92%	-92%	-158%	-158%	-208%	-208%	-354%	-354%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.30: GHG Emissions Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-9%	-17%	-24%	-12%	-16%	-21%	-12%	-16%	-20%	-12%	-15%	-20%	-12%	-15%	-20%
Price of gasoline	$/gallon	1.5	2.5	4.5	-17%	-17%	-17%	-20%	-16%	-13%	-20%	-16%	-11%	-20%	-15%	-10%	-22%	-15%	-8%
Price of electricity	$/kWh	0.06	0.1	0.25	-17%	-17%	-17%	-13%	-16%	-23%	-12%	-16%	-24%	-11%	-15%	-25%	-9%	-15%	-26%
Change in Price of Gasoline*	-	0.99	1	1.01	-17%	-17%	-17%	-16%	-16%	-16%	-16%	-16%	-15%	-16%	-15%	-14%	-16%	-15%	-14%
Change in Price of Electricity*	-	0.99	1	1.01	-17%	-17%	-17%	-16%	-16%	-17%	-15%	-16%	-16%	-15%	-15%	-16%	-15%	-15%	-17%
Discount Rate	-	3%	7%	10%	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
VMT Elasticity	-	-0.05	-0.15	-0.25	-25%	-17%	-9%	-25%	-16%	-6%	-25%	-16%	-5%	-26%	-15%	-4%	-27%	-15%	-2%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-17%	-17%	-17%	-16%	-16%	-16%	-15%	-16%	-16%	-15%	-15%	-15%	-15%	-15%	-15%
Nuclear	-	-	-	-	-	-17%	-17%	-	-16%	-39%	-	-16%	-53%	-	-15%	-64%	-	-15%	-99%
NGCC	-	-	-	-	-	-17%	-17%	-	-16%	-20%	-	-16%	-21%	-	-15%	-23%	-	-15%	-28%
COAL	-	-	-	-	-	-17%	-17%	-1%	-16%	-1%	9%	-16%	9%	16%	-15%	16%	39%	-15%	39%
VOC emissions	$/ton	210	1,090	1,980	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
CO emissions	$/ton	20	90	160	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
NOX emissions	$/ton	1,710	6,350	10,740	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
PM10 emissions	$/ton	11,430	20,260	29,100	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
PM2.5 emissions	$/ton	21,630	173,860	326,100	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
SOX emissions	$/ton	6,980	31,490	56,000	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%
GHGs	$/ton CO2-equevalent	1.5	14	70	-17%	-17%	-17%	-16%	-16%	-16%	-16%	-16%	-16%	-15%	-15%	-15%	-15%	-15%	-15%
Energy Security	$/gallon	0.02	0.37	0.63	-17%	-17%	-17%	-16%	-16%	-16%	-16%	-16%	-16%	-15%	-15%	-15%	-15%	-15%	-15%
Congestion	$/mile	0.02	0.035	0.09	-	-17%	-17%	-	-16%	-16%	-	-16%	-16%	-	-15%	-15%	-	-15%	-15%

*relative to the price of other goods and services

Gasoline Consumption Reduction Relative to CV

Table D.31: Sensitivity of Gasoline Consumption Reduction Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	66%	-60%	53%	-48%	46%	-42%	42%	-38%	34%	-31%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	4%	-3%	4%	-4%	4%	-4%	0%	0%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	-3%	8%	-3%	7%	-3%	6%	0%	0%
Change in Price of Gasoline*	-	0.99	1	1.01	1%	-1%	1%	-1%	1%	-2%	1%	-1%	1%	-1%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	0%	1%	0%	1%	0%	1%	0%	0%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	12%	-12%	10%	-10%	8%	-9%	7%	-8%	0%	0%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	27%	-17%	21%	-17%	18%	-17%	17%	-23%	24%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.32: Gasoline Consumption Reduction Relative to CV (in percent)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	-54%	-44%	-26%	-68%	-59%	-45%	-75%	-69%	-58%	-81%	-76%	-69%	-100%	-100%	-100%
Price of gasoline	$/gallon	1.5	2.5	4.5	-44%	-44%	-44%	-61%	-59%	-57%	-71%	-69%	-66%	-79%	-76%	-73%	-100%	-100%	-100%
Price of electricity	$/kWh	0.06	0.1	0.25	-44%	-44%	-44%	-57%	-59%	-63%	-66%	-69%	-74%	-74%	-76%	-81%	-100%	-100%	-100%
Change in Price of Gasoline*	-	0.99	1	1.01	-44%	-44%	-44%	-59%	-59%	-59%	-69%	-69%	-68%	-76%	-76%	-76%	-100%	-100%	-100%
Change in Price of Electricity*	-	0.99	1	1.01	-44%	-44%	-44%	-59%	-59%	-60%	-68%	-69%	-69%	-76%	-76%	-77%	-100%	-100%	-100%
Discount Rate	-	3%	7%	10%	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
VMT Elasticity	-	-0.05	-0.15	-0.25	-49%	-44%	-39%	-65%	-59%	-53%	-74%	-69%	-62%	-81%	-76%	-70%	-100%	-100%	-100%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-44%	-44%	-44%	-63%	-59%	-56%	-74%	-69%	-64%	-81%	-76%	-70%	-100%	-100%	-98%
Nuclear	-	-	-	-	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
NGCC	-	-	-	-	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
COAL	-	-	-	-	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
VOC emissions	$/ton	210	1,090	1,980	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
CO emissions	$/ton	20	90	160	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
NOX emissions	$/ton	1,710	6,350	10,740	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
PM10 emissions	$/ton	11,430	20,260	29,100	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
PM2.5 emissions	$/ton	21,630	173,860	326,100	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
SOX emissions	$/ton	6,980	31,490	56,000	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-
GHGs	$/ton CO2-equevalent	1.5	14	70	-44%	-44%	-44%	-59%	-59%	-59%	-69%	-69%	-69%	-76%	-76%	-76%	-100%	-100%	-100%
Energy Security	$/gallon	0.02	0.37	0.63	-44%	-44%	-44%	-59%	-59%	-59%	-69%	-69%	-69%	-76%	-76%	-76%	-100%	-100%	-100%
Congestion	$/mile	0.02	0.035	0.09	-	-44%	-44%	-	-59%	-59%	-	-69%	-69%	-	-76%	-76%	-	-	-

*relative to the price of other goods and services

Table D.33: Gasoline Consumption Reduction Relative to CV (in gallons)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	4,590	2,770	1,110	5,710	3,720	1,940	6,330	4,330	2,530	6,800	4,790	2,980	8,430	6,300	4,340
Price of gasoline	$/gallon	1.5	2.5	4.5	2,770	2,770	2,770	3,870	3,720	3,600	4,490	4,330	4,170	4,960	4,790	4,620	6,300	6,300	6,300
Price of electricity	$/kWh	0.06	0.1	0.25	2,770	2,770	2,770	3,610	3,720	4,000	4,190	4,330	4,630	4,640	4,790	5,090	6,300	6,300	6,300
Change in Price of Gasoline*	-	0.99	1	1.01	2,790	2,770	2,740	3,760	3,720	3,670	4,360	4,330	4,260	4,830	4,790	4,720	6,340	6,300	6,220
Change in Price of Electricity*	-	0.99	1	1.01	2,770	2,770	2,770	3,710	3,720	3,750	4,310	4,330	4,360	4,780	4,790	4,820	6,300	6,300	6,300
Discount Rate	-	3%	7%	10%	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
VMT Elasticity	-	-0.05	-0.15	-0.25	3,100	2,770	2,450	4,080	3,720	3,340	4,680	4,330	3,930	5,120	4,790	4,420	6,300	6,300	6,290
VMT distribution	-	Low VMT	Medium VMT	VMT High	2,140	2,770	3,530	3,070	3,720	4,490	3,600	4,330	5,110	3,960	4,790	5,610	4,860	6,300	7,840
Nuclear	-	-	-	-	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
NGCC	-	-	-	-	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
COAL	-	-	-	-	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
VOC emissions	$/ton	210	1,090	1,980	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
CO emissions	$/ton	20	90	160	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
NOX emissions	$/ton	1,710	6,350	10,740	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
PM10 emissions	$/ton	11,430	20,260	29,100	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
PM2.5	$/ton	21,630	173,860	326,100	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
SOX emissions	$/ton	6,980	31,490	56,000	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
GHGs	$/ton CO2-equevalent	1.5	14	70	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
Energy Security	$/gallon	0.02	0.37	0.63	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300
Congestion	$/mile	0.02	0.035	0.09	2,770	2,770	2,770	3,720	3,720	3,720	4,330	4,330	4,330	4,790	4,790	4,790	6,300	6,300	6,300

*relative to the price of other goods and services

Added VMT Relative to CV

Table D.34: Sensitivity of Added VMT Relative to CV

Parameter	Unit	Parameter Value			HEV		PHEV-20		PHEV-40		PHEV-60		BEV	
		Low	Base	High	Low	High	Low	High	Low	High	Low	High	Low	High
Fuel economy of CV	mpg	18	24.1	35	65%	-60%	28%	-34%	26%	-31%	25%	-30%	23%	-28%
Price of gasoline	$/gallon	1.5	2.5	4.5	0%	0%	-27%	24%	-31%	30%	-34%	35%	-38%	48%
Price of electricity	$/kWh	0.06	0.1	0.25	0%	0%	21%	-52%	27%	-58%	31%	-62%	41%	-67%
Change in Price of Gasoline*	-	0.99	1	1.01	1%	-1%	2%	-5%	1%	-3%	1%	-2%	0%	0%
Change in Price of Electricity*	-	0.99	1	1.01	0%	0%	2%	-4%	3%	-5%	3%	-6%	4%	-7%
Discount Rate	-	3%	7%	10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VMT Elasticity	-	-0.05	-0.15	-0.25	-67%	67%	-68%	74%	-68%	75%	-68%	75%	-69%	79%
VMT distribution	-	Low VMT	Medium VMT	VMT High	-23%	27%	-20%	25%	-20%	24%	-20%	24%	-23%	27%
Nuclear	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NGCC	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
COAL	-	-	-	-	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
VOC emissions	$/ton	210	1,090	1,980	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CO emissions	$/ton	20	90	160	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
NOX emissions	$/ton	1,710	6,350	10,740	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM10 emissions	$/ton	11,430	20,260	29,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PM2.5 emissions	$/ton	21,630	173,860	326,100	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOX emissions	$/ton	6,980	31,490	56,000	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GHGs	$/ton CO2-equevalent	1.5	14	70	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Energy Security	$/gallon	0.02	0.37	0.63	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Congestion	$/mile	0.02	0.035	0.09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

*relative to the price of other goods and services

Table D.35: Added VMT Relative to CV (in 1000 miles)

Parameter	Unit	Parameter Value			HEV			PHEV-20			PHEV-40			PHEV-60			BEV		
		Low	Medium	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High	Low	Base	High
Fuel economy of CV	mpg	18	24.1	35	40.5	24.5	9.8	36.1	28.2	18.6	39.0	31.1	21.4	40.8	32.8	22.9	44.5	36.1	25.9
Price of gasoline	$/gallon	1.5	2.5	4.5	24.5	24.5	24.5	20.6	28.2	34.9	21.3	31.1	40.5	21.7	32.8	44.2	22.3	36.1	53.4
Price of electricity	$/kWh	0.06	0.1	0.25	24.5	24.5	24.5	34.1	28.2	13.6	39.4	31.1	12.9	42.8	32.8	12.5	51.1	36.1	12.0
Change in Price of Gasoline*	-	0.99	1	1.01	24.6	24.5	24.2	28.9	28.2	26.9	31.5	31.1	30.1	33.1	32.8	32.1	36.2	36.1	36.0
Change in Price of Electricity*	-	0.99	1	1.01	24.5	24.5	24.5	28.8	28.2	27.0	31.9	31.1	29.4	33.7	32.8	30.8	37.4	36.1	33.6
Discount Rate	-	3%	7%	10%	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
VMT Elasticity	-	-0.05	-0.15	-0.25	8.2	24.5	40.8	9.0	28.2	49.0	9.9	31.1	54.3	10.4	32.8	57.5	11.2	36.1	64.8
VMT distribution	-	Low VMT	Medium VMT	VMT High	18.9	24.5	31.2	22.6	28.2	35.3	25.0	31.1	38.6	26.1	32.8	40.6	27.9	36.1	45.8
Nuclear	-	-	-	-	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
NGCC	-	-	-	-	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
COAL	-	-	-	-	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
VOC emissions	$/ton	210	1,090	1,980	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
CO emissions	$/ton	20	90	160	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
NOX emissions	$/ton	1,710	6,350	10,740	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
PM10 emissions	$/ton	11,430	20,260	29,100	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
PM2.5 emissions	$/ton	21,630	173,860	326,100	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
SOX emissions	$/ton	6,980	31,490	56,000	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
GHGs	$/ton CO2-equevalent	1.5	14	70	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
Energy Security	$/gallon	0.02	0.37	0.63	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1
Congestion	$/mile	0.02	0.035	0.09	24.5	24.5	24.5	28.2	28.2	28.2	31.1	31.1	31.1	32.8	32.8	32.8	36.1	36.1	36.1

*relative to the price of other goods and service

APPENDIX E: VMT CALCULATION FOR THE THIRD ESSAY

Using the National Household Travel Survey (NHTS) data (DOT 2001), the cumulative distribution function (CDF) of daily VMT for gasoline-powered conventional passenger cars was constructed. This distribution was adjusted for HEVs and PHEVs to recognize the fact that as the cost of driving per mile changes, so will the amount of driving that households will tend to engage in.

For analytical purposes, the empirical VMT CDF was approximated by a discrete distribution that consists of 20 blocks, each representing 5 percent of the distribution. The VMT value associated with the ith block (or quantile) is denoted $q_{t,k,i}$ where t = 0,1,… is an index indicating time or vehicle age), $k \in \{CV, HEV, PHEV\}$ is an index based upon vehicles type, and i=1,2,...,20 is an index showing the quantile of the daily VMT distribution. For example, $q_{5,CV,4}$ represents the 4th (or 20%)-quantile on the daily VMT CDF for a CV in year 5.

To model how households adjust their driving behavior as the cost of driving changes, a system of equations which vary with gasoline and electricity prices, gasoline and electricity fuel efficiency, and the initial distribution of VMT calculated from the NHTS for CVs was solved. The system of equations involves solving the following equations for the average daily VMT, $\overline{q}_{t,k}$ for each vehicle class k in year t.

Average Daily VMT Equation

The average daily VMT for vehicle type k in year t was calculated from the discrete VMT CDF as:

$$\overline{q}_{t,k} = \sum_{i=1}^{20} \frac{1}{20} q_{t,k,i} \qquad \text{(E-1)}$$

Driving Behavior Equation

The average daily amount driven was assumed to vary with the average cost of driving a mile, $ac_{t,k}$, as follows:

$$\bar{q}_{t,k} = \bar{q}_{0,CV}\left(\frac{ac_{t,k}}{ac_{0,CV}}\right)^{\varepsilon} \quad \text{(E-2)}$$

where $\varepsilon<0$ is the price elasticity of travel demand.

Average Cost of Driving per Mile Equation

The average cost of driving was calculated as follows:

$$ac_{t,k} = \frac{1}{\bar{q}_{t,k}}\sum_{i=1}^{20}\frac{1}{20}c_{t,k}(q_{t,k,i}) \quad \text{(E-3)}$$

where $c_{t,k}(q)$ is private cost of driving at time t, for vehicle k which varies with the daily driving distance q. The function $c_{t,k}(q)$ was calculated as

$$c_{t,k,i}(q) = \begin{cases} q\dfrac{p_{t,G}}{\mu_k} & \text{if } k = \{CV, HEV\} \\ q\dfrac{p_{t,E}}{\lambda} & \text{if } k = \{PHEV\} \text{ and } q \le X \\ X\dfrac{p_{t,E}}{\lambda} + (q - X)\dfrac{p_{t,G}}{\mu_k} & \text{if } k = \{PHEV\} \text{ and } q > X \end{cases} \quad \text{(E-4)}$$

where $p_{t,G}$ is the price per gallon of gasoline at time t, $p_{t,E}$ is the price per kWh of electricity at time t, μ_k is the gasoline fuel efficiency (miles/gallon) of vehicle class k, λ is the efficiency of PHEVs running on electricity (miles/kWh), and X is the distance at which PHEVs can be driven on electricity before they must switch to gasoline.

Daily VMT Adjustment Equation

Finally, it was assumed that as average daily VMT changes, the distribution of daily VMT shifted according to the following equation:

$$q_{t,k,i} = q_{0,CV,i}\left(\frac{\bar{q}_{t,k} - \bar{q}_{0,CV}}{\bar{q}_{0,CV}}\right) \quad \text{(E-5)}$$

By scaling the distribution in this way, Equation E-1 holds.

A numeric search procedure was used to solve the system of equations E-1 to E-5. The procedure iteratively seeks out values of $\bar{q}_{t,k}$ that cause all four equations to hold. The procedure was used to solve for $\bar{q}_{t,k}$ for all time periods, t, and vehicle types, k.