ABSTRACT

Title of Document: MODELING VEHICLE OWNERSHIP DECISIONS IN MARYLAND: A PRELIMINARY STATED-PREFERENCE SURVEY AND MODEL

Michael Maness, Master of Science, 2010

Directed By: Assistant Professor Cinzia Cirillo
Department of Civil and Environmental Engineering

In the near future, the culmination of new vehicle technologies, greater competition in the energy markets, and government policies to fight pollution and reduce energy consumption will result in changes in the United States' vehicle marketplace. This project proposes to create a stated preference (SP) survey along with discrete choice models to predict future demand for electric, hybrid, alternative fuel, and gasoline vehicles. The survey is divided into three parts: socioeconomics, revealed preference (RP), and SP sections. The socioeconomics portion asks respondents about themselves and their households. The RP portion asks about household's current vehicles. The SP section presents respondents with various hypothetical scenarios over a future five-year period using one of three game designs. The designs correspond to: changing vehicle technology, fuel pricing and availability, and taxation policy. With these changes to the vehicle marketplace, respondents are asked whether they will keep or replace their current vehicles and if he will purchase a new vehicle and its type. To facilitate the design and administering of the survey, a web survey framework, JULIE, was created specifically for creating stated preference surveys. A preliminary trial of the survey was conducted in September and October 2010 with a sample size of 141 respondents. Using the SP results from this preliminary trial, a multinomial logit model is used to estimate future vehicle ownership by vehicle type. The models show that the survey design allows for estimation of important parameters in vehicle choice.

MODELING VEHICLE OWNERSHIP DECISIONS IN MARYLAND: A PRELIMINARY STATED-PREFERENCE SURVEY AND MODEL

By

Michael Maness

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Advisory Committee:
Professor Cinzia Cirillo, Chair
Professor Lei Zhang
Professor David Cantor

Dedication

This paper is dedicated to my parents, Helen and Michael Maness, who have always been supportive and knew that I could do great things.

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I would like to acknowledge my advisor, Cinzia Cirillo, for the assistance she has given me in my academic progression and research endeavors. She has been a valuable guide and reference over the past four years.

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Additionally I would like to thank my friends and family for their support. And thanks to my parents for that box of traffic sign magnets when I was four years old.

I also want to acknowledge Julie Pflager for whom JULIE was named after as a joke, but I never got around to changing the name.

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Chapter 1: Introduction

American consumers are at a crossroads of various vehicle technologies in the market over the next five years. Energy prices in the 2000s rose sharply and are expected to rise steadily once the global economy fully recovers which will create a competitive marketplace for alternative energy sources. Additionally, state and national governments are interested in using public policy to reduce dependence on foreign oil, decrease air pollution, and combat climate change. These three conditions create an interesting opportunity for changes in the automotive marketplace over the next five to ten years.

Predicting consumer preferences for future vehicles is important for industry and the government. Automobile companies need to know how much and what kind of products to sell in the marketplace in order to make a profit. Transportation planners need to know the vehicle characteristics of roadways users in order to create valid car ownership models to predict energy consumption and emissions. Government officials need to know what policies can encourage vehicle ownership which promotes a better environment, improves public health, reduces energy dependence, and promotes domestic economic growth.

1.1 Objectives of the Research

The goal of this study is to present a survey life cycle which examines consumer preferences for new vehicles in the short-term automobile marketplace. This survey will examine vehicle preference for traditional gasoline vehicles as well as hybrid, alternative fuel, diesel, battery electric, and plug-in hybrid vehicles. Through the use of state choice methods, various scenarios will be used to determine the tradeoffs households place on emerging vehicle and fuel technology as well as various taxation policies.

A web-based format was chosen for the survey for its low cost and ease of data recording. In order to create stated preference surveys for online use, a web survey framework was created called JULIE. JULIE enables survey designers to create custom, flexible travel surveys for administration in both computer assisted and web-based surveys.

For this study, a preliminary survey was created to test the concept. An initial CASI trial was performed followed by a more thorough web-based trial. Data collection occurred during September and October of 2010. Results from the survey are used to infer the behavior of households in the vehicle choice process. Discrete choice methods are used to model household behavior.

This research is interdisciplinary between the fields of transportation engineering, survey methodology, econometrics, and computer science. It fits into the realm of travel behavior analysis.

1.2 Overview

Chapter 2 contains a literature review of similar studies. Stated Preference surveys are the primary focus of the literature review, but other study techniques as well as modeling approaches are looked at.

Chapter 3 discusses vehicle and fuel technology that will be relevant in the next five years. Chapter 4 describes the survey design and methodology. The socioeconomic and RP portions are described as well as the three stated choice games corresponding to vehicle technology, fuel choice, and taxation policy.

Chapter 5 describes the tool used to administer the survey. JULIE is a web-survey framework designed to allow for customized stated preference surveys to be administered in computer-assisted and web-based modes.

Chapter 6 provides some descriptive statistics to describe the sample of the survey and the responses received. Chapter 7 infers the tradeoff that households face when determining future vehicle choice decisions. Three discrete choice models are used to model the vehicle decision process.

Chapter 8 concludes the paper with a summary of the study.

Chapter 2: Literature Review

This section describes past research in new vehicle and fuel technology preference in North America, Europe, and Asia.

Train (1980) conducted multiyear simulations with alternatively-fueled vehicles and RP data. In Train's research, he analyzed battery-powered vehicles (BEVs), hybrid electric vehicles (HEVs), hydrogen vehicles (H_2Vs), and an aluminum oxidation vehicle. Likely attributes for these vehicles are projected but attributes that differ from conventional gasoline vehicles are excluded. Additionally, because he restricted his research to RP models, the alternative specific constants (ASCs) he obtains cannot be accurately estimated; Train assumes the ASCs are the same as similar sized gasoline vehicles.

Since Train's research, alternate approaches have been used to study vehicle preferences for new vehicle technology. For this project, past research was analyzed primarily from stated preference (SP) methods.

2.1 Stated Preference Studies

Use of SP surveys in determining future vehicle preferences has occurred since the early 1990s with Bunch et al. (1993). In this study, a three phase survey is performed. Recruitment occurred by random-digit dialing (RDD) with a mail-survey for the remainder of the survey. In phase one, background information was obtained from respondents.

Phase two was the vehicle choice portion of the study. Stated choice games were given to respondents (corresponding to responses given in phase one) in which they had a choice set consisting of: (1) new gasoline vehicle, new alternative-fuel vehicle (AFV), or flex-fuel vehicle AND (2) new gasoline vehicle, new AFV, or new BEV. The respondents were asked which vehicle they would purchase depending on a list of attributes. The attributes used in the vehicle choice game were fuel type, fuel availability, range between refueling, purchase price, fuel cost (price per mile), relative pollution level, and vehicle performance (relative to cars in the early 1990s).

In phase three of the Bunch et al. survey, respondents were given fuel choice games. Respondents were told that they had a flex-fuel vehicle of a given size. They were then asked to choose which fuel, gasoline or alternative-fuel, they would choose depending on the following attributes: price per gallon, range on a full tank, pollution relative to 1991 cars, and station availability (percentage of stations with the fuel). Additional models using multinomial logit (MNL) and multinomial probit (MNP) were also used.

This study included 1096 households initially which was reduced to about 569 respondents by the last phase. With a pool of 3460 observations (692 respondents and 5 games per respondent), a vehicle choice model, nested multinomial logit model (NMNL), was estimated and presented. This model included socioeconomics, preconceived notions of household preferences, vehicle pricing, fuel cost, range[1], fuel availability[1], and emissions[1]. For the fuel choice model (which was also MNL), 2208 observations were used for the estimation. A binary logit formulation was used which found significant relationships with choice and fuel cost[1], range[1], emissions[1], and station availability.

Loo (2002) analyzed the role of stated preference methods in planning sustainable urban transportation systems. She concluded that there is a need for soft, disaggregate data; attribute valuation; perception studies; and attitudinal data in planning. For car ownership, Loo said that since most alternative fuel vehicles are prototypes, SP data is essential for understanding the tradeoffs. SP methods are useful for helping to craft solutions which ensure minimal public cost, maximum cost effectiveness, and minimize the difficulties for the public during these technological and policy shifts. Additionally, she stated that combining models is essential to understanding the factors needed to be more sustainable and that stated choice methods can help determine the fundamental value system of a group of people, such as their value of the environment. Loo explained that the limitations to SP approaches are that scenario must be realistic and relevant to respondents in order to get useful results and that the data obtained is highly specific to the local context.

Kurani, Turrentine, and Sperling (1996) performed a stated choice survey with reflexive designs, where respondents reflect on their travel diary activity patterns to form custom scenarios.

[1] These attributes had quadratic relationships in the models.

Kurani et al. hypothesized that:

> Assuming the vehicle can start each day with its full range, a driving range limit on that vehicle will not be an important barrier to its purchase by a potential hybrid household.

The implication of this “hybrid household hypothesis” is that for hybrid households, every *n*th vehicle purchase will be an electric vehicle, where *n* is the number of vehicle in the household. This survey consisted of two different choice situations: (1) new gasoline vehicle or home-charged BEV and (2) reformulated gasoline, CNG, HEV, two different freeway-capable BEVs, and one neighborhood BEV (a small battery electric vehicle with short range and limited speed). Situation (1) was used to test the hybrid household hypothesis while situation (2) was a possible future market scenario. The attributes in their choice games included vehicle cost, range, refueling site, refueling time, vehicle speed, and leasing price.

The study found strong support for the hybrid household hypothesis. The range limit on only one vehicle in a hybrid household is not a binding travel constraint. Additionally, they found that electric vehicles had many attractive qualities, such as the convenience of home refueling, which made it worthwhile to own one electric vehicle. The study estimated that 38% of the respondents in their survey were hybrid households and that 35% to 40% of Californian household could be hybrid households.

Chèron and Zins (1997) performed focus group discussions and conjoint analysis tasks to analyze electric vehicle preferences. The attributes used in their study were range, maximum speed, recharge time, and cost and delay for dead battery.

Respondents were asked what attribute levels were unacceptable in their opinion and asked to weight the importance of each attribute (sum to 100%). This study used linear regression with dummies for each orthogonal profile used and rank order as the dependent variable. They found a perceived risk of dead battery to be high among respondents and suggested increases in the range of EVs was necessary.

Ewing and Sarigöllü (2000) used SP methods along with attitude analysis to study consumer preferences for new vehicles. Their study concentrated on AFVs and BEVs. The stated choice game asked respondents to choose between a new gasoline vehicle, alternative-fuel vehicle, or battery-electric vehicle. The attributes used were purchase price, annual maintenance costs, acceleration, range, refueling rate, emissions, commute time (via special lanes), and commute fuel and parking costs. They found that regulation alone was not sufficient to create demand for BEVs in Canada and that technological advance was essential. They also found that price subsidies were effective and that tax credits likely would be effective.

In Ahn et al. (2008), conjoint analysis (SP) and multiple-discrete continuous choice models were used to estimate consumer preference for AFVs. This study, with 280 respondents, asked about vehicle purchase choices with the choice set of one's current vehicle, three new vehicles (gasoline or AFV). Additionally, it asked respondents to provide their expected annual usage (mileage) after a choice was made. The attributes used in this study were fuel type (gasoline, diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG), and HEV), body type (car or light truck), maintenance cost, engine displacement (performance), fuel efficiency, and fuel price. The modeling technique used was random coefficient multiple discrete-continuous extreme value (MDCEV).

Bolduc et al. (2008) used stated choice methods with psychometric data to analyze vehicle preferences in Canada. Their research included a choice set with a conventional gasoline or diesel vehicle, a natural gas vehicle, hybrid-electric vehicle and hydrogen fuel cell vehicle (HFCV). The attributes provided to respondents were purchase price, fuel cost, station availability (percentage of stations), express lane access, emissions, and vehicle performance. Bolduc estimated an integrated choice and latent variable (ICLV) model, also known as a hybrid choice model, and found that the latent variables of environmental concern and appreciation of new vehicle features were significant influences on vehicle choice.

Mau et al. (2008) hypothesized that people's value for hybrid-electric vehicles and hydrogen fuel-cell vehicles changes as more people own them, the "neighbor effect." This study was based in Canada among households with one or more gasoline vehicles. The choice set for the SP survey included a new gasoline vehicle and a HEV or HFCV. The attributes used to describes the vehicles included market share, vehicle purchase price, fuel cost, subsidy/rebate amount, warranty coverage, range, and refueling convenience. For modeling, a MNL model feeds into a capital/technology vintage model, which tracks the evolution of capital stocs over time. It simulates technology change in four steps: (1) calculate cost for each energy source, (2) retires capital stock according to an age dependent function, (3) calculates market share for the new capital stock, (4) simulates the effects of competition among energy intensive economic sectors using an equilibrium model between macroeconomic and energy sector factors. Their analysis confirmed their hypothesis that market share of new technology affects personal vehicle preferences.

Axsen et al. (2009) surveyed households in Canada and California to compare RP-only methods with SP-RP methods in determining vehicle preferences for hybrid vehicles. This study found that statistically, RP-only and RP-dominant models performed better, but that SP-dominant models provided better estimates for policy simulations and that willingness-to-pay estimates were more realistic.

Additional studies include De Vlieger et al. (2005), who performed a SP survey in Belgium with multinomial logit and nested logit models. This study analyzed preferences for gasoline, diesel, LPG, alternative fuel, BEVs, and HFCVs. The attributes that were varied were engine type, energy source, power train/transmission, purchase cost, annual cost (including battery replacement), fuel cost, range, emission level, and trunk space. Eggers and Eggers (2010) conducted a web-based SP survey in Germany concentrated on compact and subcompact vehicles for city driving. Their choice set included a gasoline vehicle and three alternative drive train vehicles (combinations of HEV, BEV, and PHEV). Attributes included drive train technology, range, and price (compared to a gasoline vehicle). The study also tailored the scenarios to respondents brand and vehicle class preferences.

2.2 Other Approaches to Analyzing Vehicle Preference

Axsen and Kurani (2009) explored social interaction in individual's assessments of plug-in electric hybrid vehicles. In this study, 31 respondents were interviewed to analyze over 190 social and interpersonal interactions in eight different social networks in California. They analyzed effects from the five perspectives of: contagion, conformity, dissemination, translation, and reflexivity. Contagion occurs when someone enthusiastically tells everyone she knows about her PHEV. Conformity deals with people changing behavior in order to conform to societal norms or pressure. Dissemination is the intentional diffusion of information to others (i.e. test, promote, and assign value to the technology). Translation is the process of active, ongoing dialogues to interpret, negotiate, and redefine what PHEVs mean to a group of people. Reflexivity is sharing and negotiating interpretations of technology as well as lifestyle trajectories. This study found that the households most responsive to new PHEVs would be in (1) a luminal state of their lifestyle practices, (2) have basic understanding of PHEVs, and (3) find supportive pro-societal values within their social networks.

2.3 Choice Modeling in Vehicle Preference

On the modeling side, Brownstone and Train (1999) used mixed logit (ML) and mixed probit (MP) models to determine household preference for vehicle technology. They found that the ML and MP models were able to create substitution patterns that were more realistic. For example, in their forecasts, when electric vehicles were introduced into the marketplace, EVs took more market share from small gasoline vehicles and less market share from large gasoline markets.

Brownstone, Bunch, and Train (2000) discussed various modeling methods for SP studies of alternative fuel vehicles. They used multinomial logit and mixed logit (ML) models. The mixed logit models had improved fit over the logit models, and show large heterogeneity in preference for alternative fuel vehicles. Merging RP and SP data worked best as SP-only models gave implausible forecasts while RP-only models were plagued with multicollinearity and difficulties in measuring vehicle attributes.

2.4 Studies about Vehicle Technology

Axsen et al. (2010) examined the feasibility of battery technology in plug-in hybrid electric vehicles (PHEVs). PHEVs' main advantage is that they have fuel flexibility (gasoline or electric). This project found that PHEVs can achieve commercial success at a level below what experts think is necessary for adoption. When giving expert and consumers simulated design task, consumers designed PHEVs with requirements below the experts' levels.

Chapter 3: Technology Background

This section reviews vehicle and fuel technology from the past decade and expected changes over the next five years.

3.1 Vehicle Technology

Conventional gasoline vehicles are the most common vehicles in use today. Gasoline vehicles have the following characteristics:

- *Fuel*. Gasoline vehicles run on gasoline. Gasoline is a liquid fuel that is widely available.
- *Fueling*. Gasoline is pumped into a tank on-board the vehicle. Fueling takes less than five minutes typically and can take place nearly anywhere.
- *Range*. Gasoline vehicles can operate until they run out of fuel then must be refueled at a gas station.
- *Emissions*. Burning gasoline produces greenhouse gases. Emission of CO_2 is proportional to fuel consumption (inversely proportional to fuel efficiency).

Table 1 describes the average fuel efficiency of vehicles on American roads during 2007 and 2008.

Table 1 Fuel Efficiency of US Passenger Cars and Light Trucks (USDoT 2010)

	2007		2008	
	Passenger Car	Light Truck	Passenger Car	Light Truck
Average US Vehicle Fuel Efficiency (MPG)	22.5	18.0	22.6	18.1
New Vehicle Fuel Efficiency (MPG)	31.2	23.1	31.2	23.6
CAFÉ Standards (MPG)	27.5	20.7	27.5	20.7

Alternative fuel vehicles (AFVs) and **diesel vehicles** have similar characteristics to conventional gasoline vehicles.

Hybrid electric vehicles (HEVs) generate electricity from a gasoline engine. This electricity is then used to partially (or fully) propel the vehicle. A HEV is not the same as a battery electric vehicle. Hybrid vehicles have nearly the same characteristics as gasoline vehicles:

- *Fuel*. HEVs run on gasoline. When stopped, most hybrid vehicles shut-off their gasoline engine to conserve fuel.
- *Fueling*. Gasoline is pumped into a tank on-board the vehicle. Fueling takes less than five minutes typically and can take place nearly anywhere.
- *Range*. Hybrid vehicles can operate until they run out of gasoline then must be refueled at a gas station.
- *Emissions*. Burning gasoline produces greenhouse gases.

Table 2 describes the characteristics of most of the hybrid vehicles in the American vehicle marketplace during the last two quarters of 2009. HEVs come in a variety of different styles and characteristics. They vary from fuel efficient small and mid-size cars, like the Toyota Prius and Honda Civic Hybrid, to SUVs and pickup trucks, such as the Ford Explorer Hybrid and Chevrolet Silverado Hybrid. Prices are typically above their conventional gasoline counterparts. Table 3 summarizes the characteristics by EPA vehicle class.

Table 2 Hybrid Vehicle Characteristics (2009/2010)

Hybrid cars	MPG city/hwy/ combined	Price ($)	CO2 Emissions (g/km)	Size
Toyota Prius (2010)	51/48/50	22000	104	Mid-size car
Honda Insight (2010)	40/43/41	19800	103	Compact Car
Honda Civic Hybrid (2009)	40/45/42	23650	109	Compact Car
Ford Fusion Hybrid (2010)	41/36/39	27995	119	Mid-size car
Toyota Camry Hybrid (2010)	33/34/34	26150	172	Mid-size car
Nissan Altima Hybrid (2009)	35/33/34	26650	104	Mid-size car
Cadillac Escalade Hybrid (2009)	20/21/20	74085	346	SUV
Chevrolet Tahoe Hybrid (2009)	21/22/21	50445	N/A	SUV
Chevrolet Malibu Hybrid (2009)	26/34/30	26150	144	Mid-size car
Chevrolet Silverado Hybrid (2009)	21/22/21	39015	254	Pickup Truck
Chrysler Aspen Hybrid (2009)	20/22/21	46120	282	SUV
Dodge Durango Hybrid (2009)	20/22/21	45890	282	SUV
Ford Escape Hybrid (2009)	34/31/32	31395	218	SUV
GMC Sierra Hybrid (2009)	21/22/21	39365	N/A	Pickup Truck
GMC Yukon Hybrid (2009)	21/22/21	51870	268	SUV
Lexus GS 450h (2009)	22/25/23	56550	185	Mid-size car
Lexus LS 600h L (2009)	20/22/21	106035	219	Large Car
Lexus RX 400h (2009)	27/24/25	42080	192	SUV
Mazda Tribute Hybrid (2009)	34/31/32	29845	184	SUV
Mercury Mariner Hybrid (2009)	34/31/32	30090	169	SUV
Saturn Aura Hybrid (2009)	26/34/30	26325	117	Mid-size car
Saturn Vue Hybrid (2009)	25/32/28	28160	120	SUV
Toyota Highlander Hybrid (2009)	27/25/26	34700	189	SUV
Mercury Milan Hybrid (2010)	41/36/38	27500	119	Mid-size car
Lexus HS 250h (2009)	35/34/34	32000	163	Large Car

Table 3 Summary Statistics for Hybrid Cars by Size

	Median MPG	Median Price ($)
Compact	41.5	21725
Mid-Size	34	26487.5
Large	27.5	69017.5
SUV	21	40295
Pickup	20	39190

Battery electric vehicles (BEV) are run by electricity stored in the vehicle's batteries. These batteries are charged (typically at home) and no liquid fuel (such as gasoline) is needed to fuel this vehicle. A BEV is not the same as a HEV. Electric vehicles have the following characteristics:

- *Fuel*. BEVs run on electricity stored in the vehicle's batteries. This electricity typically comes from the power grid, such as an outdoor wall socket/outlet.
- *Fueling*. The vehicle's batteries are charged by plugging into a wall socket/outlet for a few hours. Generally, special chargers are used to speed up the charging process.
- *Range*. Electric vehicles can operate until their batteries are depleted. Then the batteries must be recharged for 2-6 hours.
- *Emissions*. BEVs produce no direct emissions from their operation. The actual emission levels of BEVs depend on the source of electricity. In Maryland, electricity is produced by coal (emits greenhouse gases) and nuclear power (no GHG emissions).

Mass produced battery electric vehicles first entered the American marketplace near the end of 2010. Because of a lack of BEVs in the marketplace, information about possible BEV offering is difficult to find. Table 4 describes some BEVs that could enter the marketplace over the next five years.

Table 4 Electric Vehicle Characteristics

	Range (miles)	Price ($)	Seating	Additional Notes
Nissan Leaf	100	25,000 – 33,000	5	Unsure about size, based on Nissan Versa platform
Th!nk City	130	15,000 – 17,000	4	$100-$200 battery lease to reduce price
The Kurrent	35-40	9,800	2	Community EV, 35 mph or less
Mitsubishi iMiEV	80-100	N/A	4	
Pininfarina Bluecar	155	23,800	4-5	
Smart Fortwo ED	68-71	N/A	2	Likely cost less than $20,000
Tesla Model S	160,240, 300	57,400 – 60,000	5	Hopeful that price will be down to $30,000 by 2012

Plug-in hybrid electric vehicles (PHEVs) run on electricity stored in the vehicle's batteries but can also generate electricity by burning gasoline. Batteries are charged (typically at home) but PHEVs typically have a shorter electric-only range than BEVs. PHEVs have the following characteristics:

- *Fuel*. BEVs run on electricity stored in the vehicle's batteries. This electricity typically comes from the power grid, such as an outdoor wall socket/outlet. When the stored electricity runs out, the on-board gasoline engine will charge the batteries similar to a HEV.
- *Fueling*. The vehicle's batteries are charged by plugging into a wall socket/outlet for a few hours. Generally, special chargers are used to speed up the charging process. To power the gasoline engine, gasoline is pumped into a tank on-board the vehicle. Fueling takes less than five minutes typically and can take place nearly anywhere.

- *Range*. Electric vehicles can operate until their batteries are depleted. Then the batteries must be recharged for 2-6 hours. Ranges are typically shorter than BEVs.
- *Emissions*. PHEVs produce no direct emissions when operating in electric-only mode. Otherwise, emission levels are similar to a HEV.

3.2 Fuel Pricing

Figure 1 from the US Department of Energy summarizes energy prices for gasoline and ethanol (E85) from 2005 to 2009. Prices rose sharply in 2007 and 2008 before a steep drop once the US financial crisis began. E85 prices tend to follow gasoline prices at about 10% to 20% less per gallon.

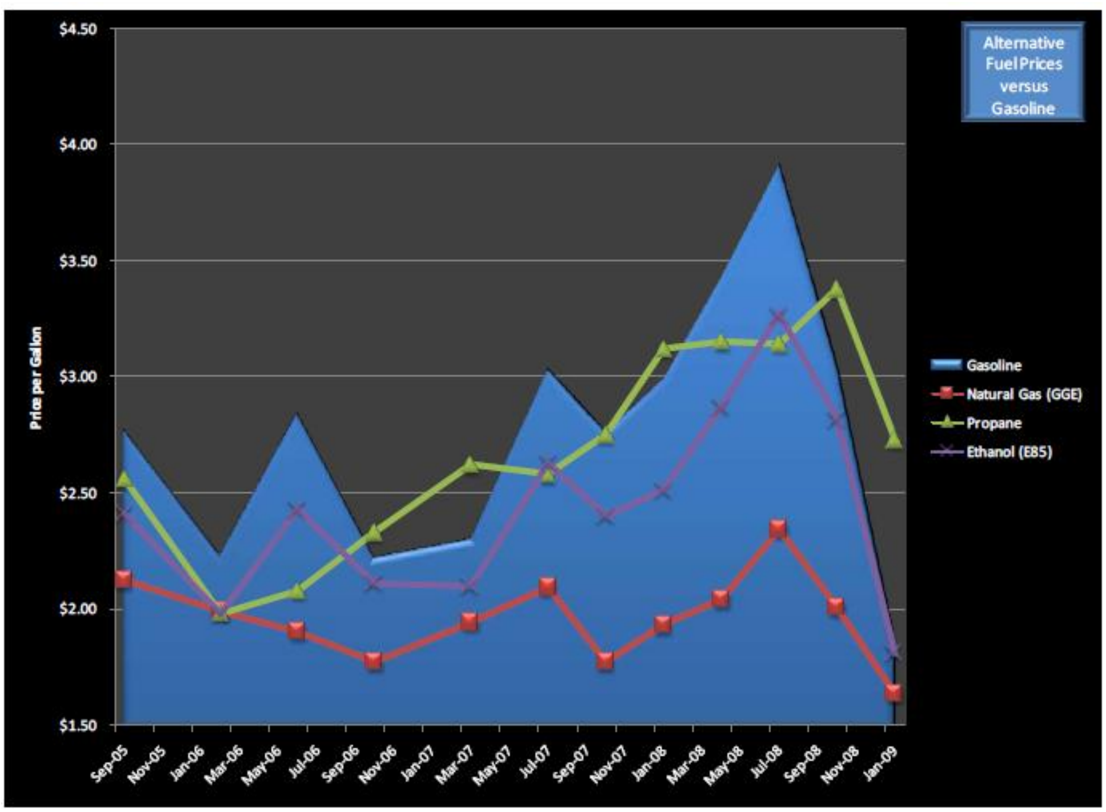


Figure 1 Alternative Fuel Prices versus Gasoline (USDoE)

Chapter 4: Survey Design & Methodology

A survey was created to obtain socioeconomic, revealed preference (RP), and SP information from respondents. The survey consisted of approximately 50 questions. A printed version of the survey is available in Appendix A. The survey was divided into three parts:

- Household Characteristics
- Current Vehicle
- Stated Preference Game

4.1 Household Characteristics

The *Household Characteristics* section gathers data about the respondent and his household. The respondent is asked to describe her socioeconomic situation via the following constructs:

- *Gender*
- *Age*
- *Education Level*
- *Head of Household*
- *Work Status*
- *Driver's License*
- *Commute Distance*
- *Work Parking*

Household data is also gathered in the following areas:

- *Household Income*
- *Number of Kids*
- *Number of Adolescents*
- *Number of Adults*
- *Number of Workers*
- *Household Location*
- *Home Type*
- *Home Parking*

4.2 Current Vehicle

The *Current Vehicle* section is provided to gather data on a respondent's primary vehicle characteristics for possible use in the SP games and modeling. A secondary purpose for this section was to analyze respondent's knowledge of their own vehicles. This section has questions involving the following:

- *Five-Year Vehicle Purchase Plans*
- *Number of Vehicles*
- *Make/Model of Vehicles*
- *Vehicle Type*
- *Model Year*
- *Purchase Year*
- *Miles Traveled per Year*
- *Fuel Type*
- *Price*
- *Fuel Economy*
- *Tank Capacity*
- *Seating Capacity*

4.3 Stated Preference

The stated preference (SP) portion of the survey involves presenting respondent with one of three stated choice experiments: (1) *Vehicle Technology,* (2) *Fuel Technology*, and (3) *Taxation Policy*. Each respondent randomly receives one SP game in section three of the survey. Game (1) has a 50% chance of being picked while games (2) and (3) each have a 25% chance.

Each stated choice game generates multiple SP obseravtions over a six year time period, from 2010 to 2015. The variables in the scenarios change from year to year when plausible. For example, vehicle price generally increases over time, hybrid tax credit decreases with time, and the range for gasoline vehicles remains constant. Two scenarios per year are presented for a total of 12 observations. Appendix E provides the orthogonal arrays used for the scenarios in each stated choice game.

Respondents are given the following instructions for this section:

- Make realistic decisions. Act as if you were actually buying a vehicle in a real life purchasing situation.
- Take into account the situations presented during the scenarios. If you would not normally consider buying a vehicle, then do not. But if the situation presented would make you reconsider in real life, then take them into account.
- Assume that you maintain your current living situation with moderate increases in income from year to year.
- Each scenario is independent from one another. Do not take into account the decisions you made in former scenarios. For example, if you purchase a vehicle in 2011, then in the next scenario forget about the new vehicle and just assume you have your current real life vehicle.

4.3.1 Game 1 – Vehicle Technology

The vehicle technology game focuses on presenting respondents with different characteristics for the vehicles and pricing to discover preferences for vehicle technology. This game design consists of four alternatives and five variables. Each variable has 16 – 24 levels of variation per alternative (four levels per vehicle size). Respondents have a choice set size of eight.

Four alternatives – current vehicle and a new gasoline, hybrid, and electric vehicle – are shown to respondents. These alternative vehicle platforms were chosen because they appear to have the best chance for market share in the United States over the next five years. Gasoline vehicles are the traditional option, while hybrid vehicles have grown in market share, led by the Toyota Prius, in the US. While electric vehicles are new to the marketplace, there has been significant interest in exploring this paradigm by major automobile manufacturers, such as the Nissan Leaf.

The variables of interest in the vehicle technology game include: vehicle price, fuel economy, refueling range, emissions, and vehicle size.

Vehicle price is a major deciding factor in the household vehicle purchase process. Prices, presented as a cost in U.S. dollars, depend on the size of the vehicle and increase from year to year. For gasoline and hybrid vehicles, the base price was determined from the average vehicle price for each vehicle type and size. For electric vehicles, the base price was determined by averaging the projected price of future electric vehicles and/or European prices (if a similar vehicle is sold in Europe). This base price is increased by 2% per year. From this base price, the other three levels are determined by increasing the base price by 4.5%, 9%, and 18%.

Vehicle fuel economy, specified in miles per gallon (MPG), has an impact on the operating cost of a vehicle which is important to households. Fuel economy is presented in miles per gallon for the gasoline and hybrid vehicles. For electric vehicles, the fuel economy is not presented (when research began, a standard for displaying fuel economy of electric vehicles was not established by the

Environmental Protection Agency or US Department of Energy). Fuel economy begins with a base value that is the average of current vehicle economy per vehicle type and class. This base remained the same from 2010 to 2015 because average fuel economy has a recent history of maintaining relatively constant. The fuel economy for the other three classes varies linearly from factors of 1.07, 1.13, and 1.18 in 2010 to factors of 1.10, 1.25, and 1.50 respectively in 2015. This formulation accounts for the uncertainty in fuel pricing over the next five years. This could result in a situation of low fuel prices and price volatility which may cause less incentive to increase fuel economy, or high fuel prices and price volatility which encourage investment in improving fuel efficiency.

A vehicle's range, specified in miles between refueling periods, is theorized to be a deciding factor in the adoption of electric vehicles due to commute distances and their long recharge times. Gasoline and hybrid vehicle tend to have refueling ranges of approximately 300-500 miles. Electric vehicles have refueling ranges primarily dependent on vehicle size. In this stated choice game, the refueling range for gasoline and hybrid vehicles do not vary over time. For electric vehicles, the range levels chosen are dependent on projected ranges for current and future vehicles. The levels are set in 2010 and are generally increased geometrically by a factor between 1.05 and 1.1 depending on the detail of data collected on range estimates by size.

A vehicle emissions variable was included to test if emission levels significantly influenced household vehicle purchasing decisions. Displaying emissions to responses can be done in various ways but the survey designers were unsure how people interpreted this data. For example, the EPA presents emissions according to carbon footprint (annual tons of CO_2) and an Air Pollution Score (10 point scale corresponding to other pollutants such as CO and NO_x). Because of these varying techniques, it was decided that vehicle emissions would be presented as a percent difference versus the average 2010 vehicle. This was primarily determined through the carbon footprint of the average 2010 vehicle (about 24 mpg) and scaled according to the fuel economy expected for a vehicle in the vehicle type and size. Electric vehicles levels for emissions were zero and the respondent was told that electric vehicles had no direct emissions.

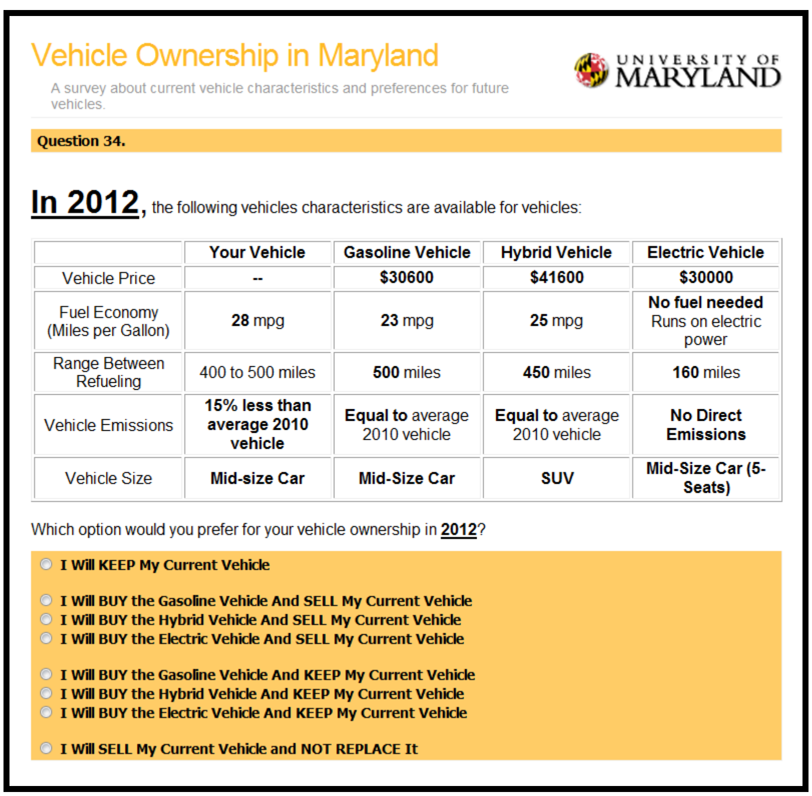
Vehicle size can be a limiting factor in the decision process due to household size and personal preferences. Additionally, size has some correlation to price, fuel economy, and emissions. The sizes chosen (6 for gasoline, 4 for hybrid and electric) are based only on designs that could be found in literature. The size system used is an abbreviated version of the EPA size class: small/compact car, midsize car, large car, minivan, sports utility vehicle, and pickup truck.

The choice set for the vehicle technology experiment includes all permutation of buying or not buying a new vehicle (gasoline, hybrid, or electric) and selling or retaining the current vehicle. This amounts to 8 possible choices.

Appendix B provides the experimental design for the vehicle technology game. A summary of the vehicle technology game is available in Table 5.

Table 5 Vehicle Technology Game Summary

Variables	• Vehicle Price • Fuel Economy • Refueling Range • Emissions • Vehicle Size
Alternatives Shown	• Current Vehicle • New Gasoline Vehicle • New Hybrid Vehicle • New Electric Vehicle
Choice Set	• I Will KEEP My Current Vehicle • I Will BUY the Gasoline Vehicle And SELL My Current Vehicle • I Will BUY the Hybrid Vehicle And SELL My Current Vehicle • I Will BUY the Electric Vehicle And SELL My Current Vehicle • I Will BUY the Gasoline Vehicle And KEEP My Current Vehicle • I Will BUY the Hybrid Vehicle And KEEP My Current Vehicle • I Will BUY the Electric Vehicle And KEEP My Current Vehicle • I Will SELL My Current Vehicle and NOT REPLACE IT


Vehicle Ownership in Maryland

A survey about current vehicle characteristics and preferences for future vehicles.

UNIVERSITY OF MARYLAND

Question 34.

In 2012, the following vehicles characteristics are available for vehicles:

	Your Vehicle	Gasoline Vehicle	Hybrid Vehicle	Electric Vehicle
Vehicle Price	--	$30600	$41600	$30000
Fuel Economy (Miles per Gallon)	28 mpg	23 mpg	25 mpg	No fuel needed Runs on electric power
Range Between Refueling	400 to 500 miles	500 miles	450 miles	160 miles
Vehicle Emissions	15% less than average 2010 vehicle	Equal to average 2010 vehicle	Equal to average 2010 vehicle	No Direct Emissions
Vehicle Size	Mid-size Car	Mid-Size Car	SUV	Mid-Size Car (5-Seats)

Which option would you prefer for your vehicle ownership in 2012?

- I Will KEEP My Current Vehicle
- I Will BUY the Gasoline Vehicle And SELL My Current Vehicle
- I Will BUY the Hybrid Vehicle And SELL My Current Vehicle
- I Will BUY the Electric Vehicle And SELL My Current Vehicle
- I Will BUY the Gasoline Vehicle And KEEP My Current Vehicle
- I Will BUY the Hybrid Vehicle And KEEP My Current Vehicle
- I Will BUY the Electric Vehicle And KEEP My Current Vehicle
- I Will SELL My Current Vehicle and NOT REPLACE It

Figure 2 Example of Vehicle Technology Scenario

4.3.2 Game 2 – Fuel Technology

The fuel type game presents respondents with different fuel options to infer the effect of fuel characteristics on future vehicle purchases. This game design consists of four alternatives and four variables. Each variable has three or six levels of variation per alternative. Respondents have a choice set size of seven.

The four alternatives (fuel types) shown to respondents are: gasoline, alternative, diesel, and electricity. These fuel types are currently established in Maryland's marketplace – gasoline via gas stations, alternative (ethanol, E85) via some gas stations, diesel via some gas stations, and electricity via the home.

The variables of interest in the fuel type game include: fuel price, fuel tax, average fuel economy, and refueling availability.

Fuel price (pre-tax) is a major component of the operating cost of a vehicle. It is presented to respondents as measured in US dollars per unit of energy. For gasoline, the price is in dollars per gallon of gasoline. For alternative fuel, the price is in dollars per gallon of alternative fuel. For diesel, the price is in dollars per gallon of diesel fuel. For electricity, the price is in dollars for 33.7 kWh of electricity, which is the electrical equivalent of the energy in one gallon of gasoline. The fuel price for the liquid fuels (gasoline, alternative, and diesel) is based on historical data in the Mid-Atlantic region, mostly from the US Department of Energy. For example, gasoline and diesel prices range from $2.00 to $4.00 in 2010. Alternative fuel prices, which are based on E85, are 10% less than gasoline prices based on historical data (due to subsidies and lower energy density). Electricity prices for 2010 scenarios are based on residential prices in Maryland during June 2009 and a four cent per KWh change in price for the levels. The prices were assumed to vary geometrically at an annual rate of 1.10 for liquid fuels and 1.03 for electricity.

Fuel tax, measured in dollars per fuel unit, contributes to the total cost of fuel. The fuel tax varied by three levels, the current tax and two higher tax rates. Tax levels did not change annually because there has been no history in Maryland of tying fuel tax rates to inflation.

Fuel efficiency affects how much fuel is used per mile traveled and is used to give respondents an idea of how efficient their vehicle choice could be in fuel economy. The fuel efficiency presented to the respondent is intended to be for a vehicle they could afford. For liquid fuels, the fuel efficiency base level is based on current data regarding average fuel economy in the US by fuel type with one level being higher and one level being lower. Electric efficiency was difficult to find as there are varying methods of presenting the efficiency of electric vehicles. Therefore the base vehicle used was the preliminary fuel economy sticker from a Mini E, which has a fuel efficiency of 100 miles per gallon equivalent (MPGe). To be conservative, the other two levels for electric fuel efficiency were lower. Fuel efficiency was assumed to increase annually by 2 mpg for gasoline and diesel, 1 mpg for alternative fuel, and 5 mpge for electricity.

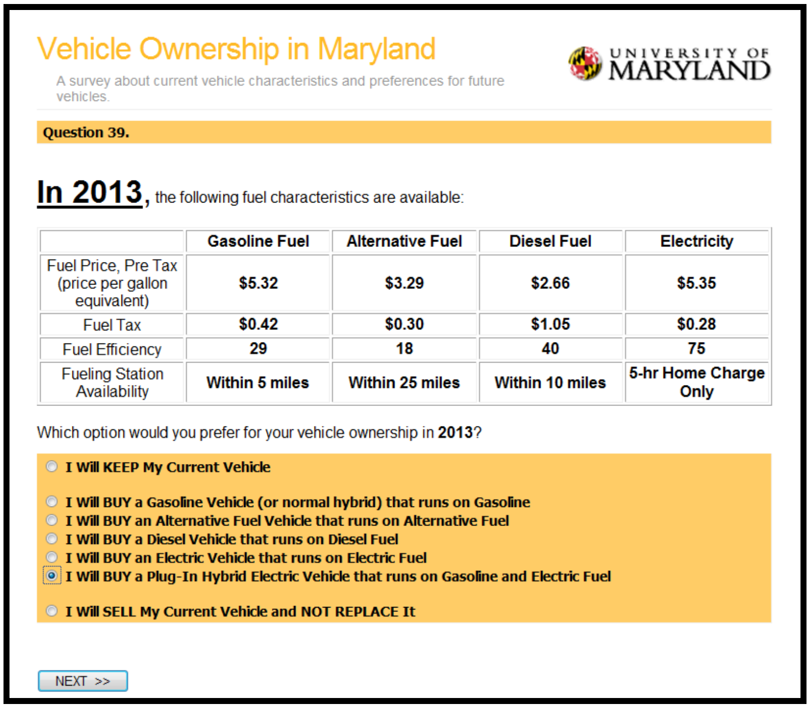
Fueling station availability may influence the choice of fueling technology. Availability was represented by the distance from home to the nearest fueling station for liquid fuels and the time to charge the vehicle at home for electricity. This variable does not change over time for gasoline and diesel fuels. Availability increases (distance from home decreases) for alternative fuel over time and the charging time decreases over time for electricity.

The choice set for this game includes keeping and selling the respondent's current vehicle or buying a new vehicle that runs on one of the fuel choices.

Appendix C provides the experimental design for the fuel type game. A summary of the fuel type game is available in Table 6.

Table 6 Fuel Technology Game Summary

Variables	• Fuel Price, Before Tax • Fuel Tax • Fuel Efficiency • Fueling Station Availability
Alternatives Shown	• Gasoline Fuel • Alternative Fuel • Diesel Fuel • Electricity
Choice Set	• I Will KEEP My Current Vehicle • I Will BUY a Gasoline Vehicle (or normal hybrid) that runs on Gasoline • I Will BUY an Alternative Fuel Vehicle that runs on Alternative Fuel • I Will BUY a Diesel Vehicle that runs on Diesel Fuel • I Will BUY an Electric Vehicle that runs on Electric Fuel • I Will BUY a Plug-In Hybrid Electric Vehicle that runs on Gasoline and Electric Fuel • I Will SELL My Current Vehicle and NOT REPLACE IT


Vehicle Ownership in Maryland

A survey about current vehicle characteristics and preferences for future vehicles.

UNIVERSITY OF MARYLAND

Question 39.

In 2013, the following fuel characteristics are available:

	Gasoline Fuel	Alternative Fuel	Diesel Fuel	Electricity
Fuel Price, Pre Tax (price per gallon equivalent)	$5.32	$3.29	$2.66	$5.35
Fuel Tax	$0.42	$0.30	$1.05	$0.28
Fuel Efficiency	29	18	40	75
Fueling Station Availability	Within 5 miles	Within 25 miles	Within 10 miles	5-hr Home Charge Only

Which option would you prefer for your vehicle ownership in **2013**?

- I Will KEEP My Current Vehicle
- I Will BUY a Gasoline Vehicle (or normal hybrid) that runs on Gasoline
- I Will BUY an Alternative Fuel Vehicle that runs on Alternative Fuel
- I Will BUY a Diesel Vehicle that runs on Diesel Fuel
- I Will BUY an Electric Vehicle that runs on Electric Fuel
- I Will BUY a Plug-In Hybrid Electric Vehicle that runs on Gasoline and Electric Fuel
- I Will SELL My Current Vehicle and NOT REPLACE It

NEXT >>

Figure 3 Fuel Technology Game Example

4.3.3 Game 3 – Taxation Policy

The taxation policy game presents respondents with different toll and tax policies to infer their effect on future vehicle purchases. For the 2010 and 2011 scenarios, the game design consists of four alternatives and two variables with three levels of variation per alternative. The choice set size is eight. For the 2012 through 2015 scenarios, the game design consists of four alternatives, three variables with three levels of variation per alternative, and nine choices.

Four alternatives – current vehicle and a new gasoline, hybrid, and electric vehicle – are shown to respondents. These alternative vehicle platforms were chosen because they appear to have the best opportunities for market share in the United States over the next five years.

The variables of interest in the tolling and taxing game include: income tax credits, toll cost, and vehicle-miles traveled (VMT) tax rate (2012-2015).

The income tax credit, measured in US dollars, attempts to encourage adoption of new technology through reducing one's tax burden. Tax credits are shown for hybrid and electric vehicles based on current federal guidelines for credits.

The toll policy variable attempts to encourage adoption of new technology by reducing toll costs for users of that technology. This variable is presented to respondents as the percent reduction in normal toll prices for users of that vehicle type. Only hybrid and electric vehicles were given reductions with a higher reduction assumed for electric vehicles since it is a newer technology.

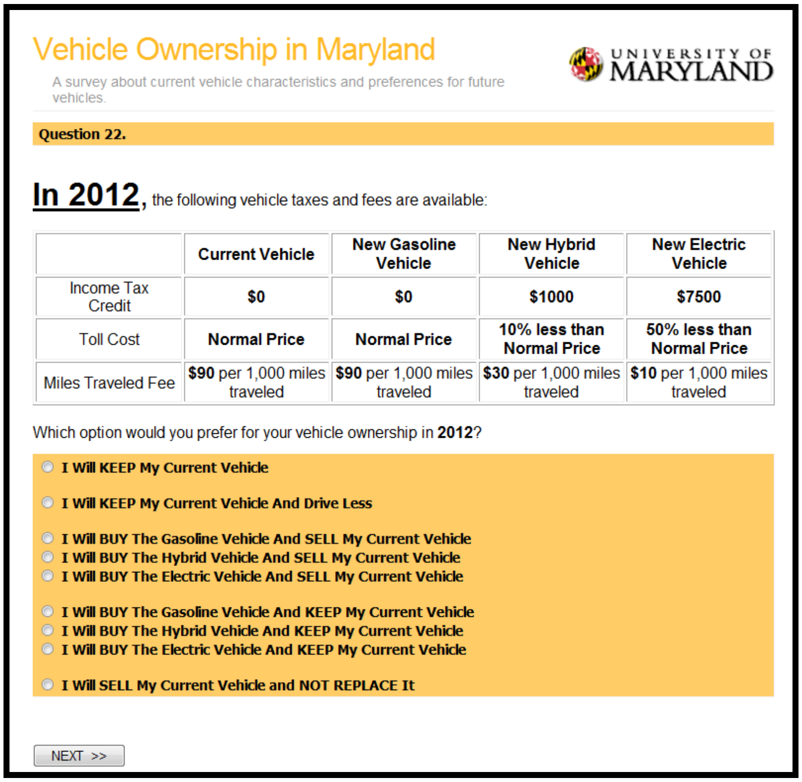
The VMT tax tries to encourage adoption of new technology by reducing the operating cost of using the vehicle. The VMT tax rate is presented as a cost (in US dollars) per 1000 miles traveled that is collected by the respondent's insurance provider. The initial rate chosen is based on data from research by the Virginia Department of Transportation. Higher rate were added to see if it could discourage gasoline usage. The rates chosen range from 1 to 10 cents per mile ($10 – $100 per 1000 miles).

The choice set for the taxation policy experiment includes all permutation of buying a new vehicle (gasoline, hybrid, or electric) or not buying and selling or retaining the current vehicle. This amounts to 8 possible choices for 2010 and 2011 scenarios. For the 2012 through 2015 scenario, an additional choice is added to keep one's current vehicle and drive less.

Appendix D provides the experimental design for the VMT, tolling, and tax credit game. A summary of the taxation policy game is available in Table 7.

Table 7 Taxation and Toll Policy Game Summary

Variables	• Income Tax Credit • Toll Price • VMT Tax (2012-2015)
Alternatives Shown	• Current Vehicle • New Gasoline Vehicle • New Hybrid Vehicle • New Electric Vehicle
Choice Set	• I Will KEEP My Current Vehicle • I Will KEEP My Current Vehicle and DRIVE LESS (2012-2015) • I Will BUY the Gasoline Vehicle And SELL My Current Vehicle • I Will BUY the Hybrid Vehicle And SELL My Current Vehicle • I Will BUY the Electric Vehicle And SELL My Current Vehicle • I Will BUY the Gasoline Vehicle And KEEP My Current Vehicle • I Will BUY the Hybrid Vehicle And KEEP My Current Vehicle • I Will BUY the Electric Vehicle And KEEP My Current Vehicle • I Will SELL My Current Vehicle and NOT REPLACE It



Vehicle Ownership in Maryland

A survey about current vehicle characteristics and preferences for future vehicles.

UNIVERSITY OF MARYLAND

Question 22.

In 2012, the following vehicle taxes and fees are available:

	Current Vehicle	New Gasoline Vehicle	New Hybrid Vehicle	New Electric Vehicle
Income Tax Credit	**$0**	**$0**	**$1000**	**$7500**
Toll Cost	**Normal Price**	**Normal Price**	**10% less than Normal Price**	**50% less than Normal Price**
Miles Traveled Fee	**$90** per 1,000 miles traveled	**$90** per 1,000 miles traveled	**$30** per 1,000 miles traveled	**$10** per 1,000 miles traveled

Which option would you prefer for your vehicle ownership in **2012**?

- **I Will KEEP My Current Vehicle**
- **I Will KEEP My Current Vehicle And Drive Less**
- **I Will BUY The Gasoline Vehicle And SELL My Current Vehicle**
- **I Will BUY The Hybrid Vehicle And SELL My Current Vehicle**
- **I Will BUY The Electric Vehicle And SELL My Current Vehicle**
- **I Will BUY The Gasoline Vehicle And KEEP My Current Vehicle**
- **I Will BUY The Hybrid Vehicle And KEEP My Current Vehicle**
- **I Will BUY The Electric Vehicle And KEEP My Current Vehicle**
- **I Will SELL My Current Vehicle and NOT REPLACE It**

NEXT >>

Figure 4 Taxation Policy Game Example

4.4 Survey Methodology

Table 8 Summary of the Survey

Purpose	Main objectives are to: • Collect data on household vehicle characteristics and future vehicle preferences in Maryland • Determine the feasibility of administering web surveys for travel surveys in Maryland
Time Frame	Summer – Fall 2010
Target Population	Suburban and Urban Maryland Households
Sampling Frame	Households with internet access in 5 Maryland counties
Sample Design	Multi-stage cluster design by county and zipcode
Use of Interviewer	Interviewer-administered for field trial, otherwise self-administered
Mode of Administration	Face-to-face interview for field trial, self-administered via the internet for remaining respondents
Computer Assistance	Computer-assisted self interview (CASI) for field trial, web-based survey for remainder of responses
Reporting Unit	One person age 18 or older per household reports for the entire household
Time Dimension	Cross-sectional survey
Frequency	One two-month phase of collecting responses
Interviews per Round of Survey	Once
Levels of Observation	Household, vehicle, person

Table 8 summarizes the characteristics and methodology of the survey. This section will describe the survey life cycle and the error sources for the survey.

4.4.1 Survey Life Cycle from a Design Perspective

The survey life cycle involves designing a process which represents what one is trying to infer about a population (representation) and the actual methods used to measure this (measurement). Figure 5 describes the survey life cycle from the design perspective

On the measurement side, the survey progresses from construct to measurement to response to edited response. The construct for this survey is to determine the utility (trade-off) households place on different vehicles. The measurement process used will include socioeconomic questions, current vehicle characteristic (RP) questions, and stated choice games (SP). The response involves various means including provided choice and recall. In edited response, some questions will be subject to range checks during survey administering, and some responses may be modified when users do not know the answer or skip questions during the data analysis phase.

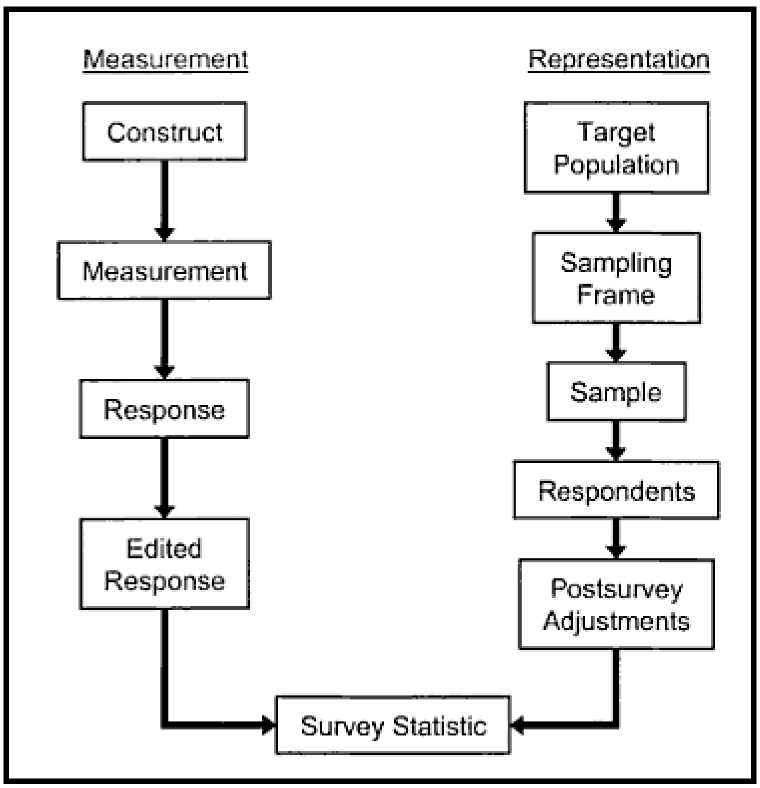


Figure 5 Survey Life Cycle from the Design Perspective (Groves et al. 2009)

The representation side of the life cycle involves target population, frame population, the sample, respondents, and postsurvey adjustments. The *target population* is residents in suburban and urban Maryland. The *frame population* is suburban and urban households in Montgomery, Prince George's, Howard, and Anne Arundel

Counties and Baltimore City with internet access. The *sample* includes household from the above counties and city clustered by zip code. For *respondents*, approximately 1700 households were contacted with 154 households participating in the survey (9% response rate). Of these 154 households, 141 completed the survey (93% completion rate). During *postsurvey adjustments*, weighting according to county population size was considered but not used for the discrete choice models. Weighting in discrete choice models is not extensively performed in the field and many software packages for estimating discrete choice models do not allow for different weighting procedures. Additionally, some imputation procedures will be used to deal with item non-response.

The survey statistic in this survey will be the parameter coefficients for three different discrete choice models corresponding to the three SP games. In this report, the estimated parameters are shown along with their corresponding t-statistics.

4.4.2 Survey Life Cycle from a Quality Perspective

Figure 6 describes the life cycle process from a quality perspective with boxes representing the design perspective (measurable statistics and theoretical ideas) and ovals representing sources of error along the life cycle.

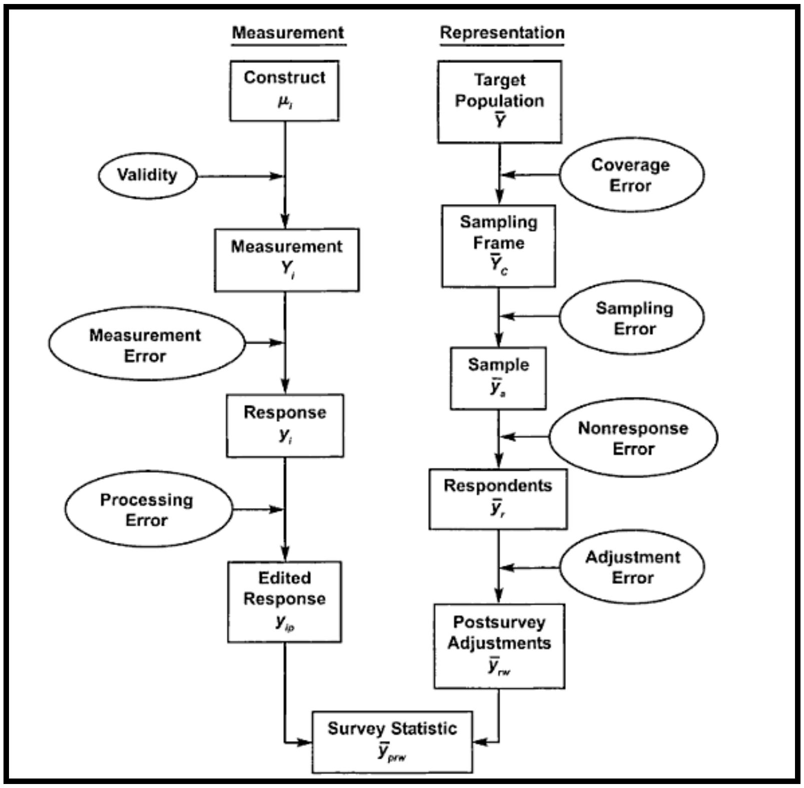


Figure 6 Survey Life Cycle from a Quality Perspective (Groves et al. 2009)

The *validity* of the construct is challenged by an inability to account for factors which we cannot measure or were unable to measure effectively via the web interface. Additionally, there may be factors which we do not know matter to some respondents. The discrete choice modeling process attempts to deal with these factors by assuming that the factors are stochastic.

Measurement error during the stated choice games involves differing responses from true choices. Respondents would have a larger number of variables to consider and more time to make choices in real conditions, and future behavior is inherently unstable. Also, there may be an overreporting of alternative vehicle preferences since respondents may try to appear environmentally conscious or give into societal pressure (social desirability bias). Using a self-administered survey attempts to alleviate this concern.

Additional sources of measurement errors may include some vehicle characteristics questions in which respondents are required to use recall. Respondents may not know the true answers to these questions or may attempt to estimate their values.

Processing error is limited in this survey as most questions are closed-form. There may be coding problems in the vehicle make and model questions, as these are the only open-ended questions in the survey.

Coverage error involves both undercoverage and ineligible units. In 2007, 66% of Maryland homes had internet access (NTIA 2008). Internet usage is skewed towards households with greater income, higher education, and towards middle-age persons. Additionally, African-American and Hispanic households have a lower rate of internet usage at home.

Ineligible units also may cause some coverage errors. Households from outside the coverage area, in other counties and states, participated in the survey. This type of ineligibility is difficult to prevent due to the open nature of the Internet. Ineligible units were still used for estimation since this survey was a preliminary field trial.

Sampling error involved sampling bias and sampling variance. The sampling bias in this survey is biased towards the characteristics of households with internet access (educated, affluent). This bias will induce a corresponding increase in variance, so some estimates that are insignificant could possibly be significant in a simple random sample of the same size.

Nonresponse error is expected because of a low response rate due to the survey being voluntary. Some respondents that were recruited may not have the internet. Additionally there was no incentive provided so there may be a skew towards people with an interest in new vehicle technology. Additionally item nonresponse may occur since respondents are allowed to skip questions.

Adjustment error is not expected as no adjustments were made to weigh different respondents. This was done because of the assumption of a simple random sample that is necessary for the discrete choice methods used in this survey. Additionally, because of the small sample size and the preliminary nature of the survey, it was felt that weighting was unnecessary since policy analysis is not a part of this study.

4.4.3 Sample Design

A two stage cluster design was used for this survey. Households were clustered by county then zip code. This approach was used for cost and human capital reasons.

Because there is no universally available frame of all Maryland residents with internet access, creating an appropriate frame would be too expensive. Additionally, obtaining a frame of all residential addresses in Maryland was considered to also be too expensive. A clustered design was determined to be within the project's cost and time budgets.

In terms of the survey's manpower, a limited amount of human capital was available. Most members of the survey team were volunteers with full time student schedules. Work availability was limited to weekend and the conveniences of the volunteers. A cluster design with self-administered surveys would be the easiest technique for this workforce since it could reduce workers time and travel commitments. The first trial began with computer assisted personal interview (CASI) data collection which entailed a large time commitment for volunteers. Web-based administration was performed after this initial trial.

The limitations of the workforce also meant that the choice of zip code clusters was delegated to the volunteers since they needed to be able to access areas and feel safe and unburdened. Therefore there may be some sampling error from this technique as some biases may develop from a pseudo-random clustering of zip codes. Volunteers were also allowed to decide on the recruitment method in those zip codes. The methods of recruitment were limited to door-to-door flyer handouts and flyer handouts at a local gathering place (e.g. mall, supermarket). The former method meant that some respondents from outside of the target area were recruited which also introduces some sampling error. The distribution of respondent locations is available in Appendix F.

4.5 Contributions

This survey makes the following difference with similar surveys in the SP car ownership literature:

- *Time of Purchase.* Respondents are given a six year time window to make various purchases. Prior surveys looked at either a set time (e.g. in the next 6 months) or the next vehicle purchase. Thus this survey essentially uses time as an attribute in the scenarios.

- *Keeping Current Vehicle.* The choice set of this survey includes the option of keeping one's current vehicle. Few surveys included this option as most just analyzed the next vehicle purchase, whenever that may occur.

- *Plug-in Hybrid Electric Vehicles.* Plug-in hybrid vehicles have not been extensively researched through SP methods. It was more common to analyze flex-fuel vehicles (run on gasoline and an alternative fuel) in the literature.

- *Exclusion of Models.* Various vehicle options seem unlikely for a household are not excluded from SP scenarios. For example, a household with many children was still given the option of buying a two-seat electric vehicle or a compact hybrid vehicle. Many surveys such as Bunch et al. (1993) excluded vehicle sizes which respondents said they would not purchase. We decided to not exclude models because of the possibility of unexpected volatility over the next five years in vehicle offerings and fuel prices which may cause household to rethink their vehicle needs.

- *Dynamic Attributes.* The attributes change from year to year which was not common in prior literature. For example, BEV prices fall over the next three years or gasoline vehicle MPG increases annually. This allows to analyze if there are possible "tipping points" in technological and price changes which may influence new vehicle adoption.

- *Inclusion of Respondents.* All respondents are included in the SP surveys, whether they intend to buy a new vehicle over the next five years or not. Some surveys only analyzed respondents who intended to buy vehicles or had an interest in alternative vehicle technology (e.g. Bunch et al (1993), Kurani et al. (1996)).

Chapter 5: JULIE – Web Survey Framework

Online survey software is available from commercial and open-source providers for performing web-based surveys. These services provide simple questions formats (e.g. multiple choice, open-ended) and basic question ordering functions. This leaves them well suited for simple travel surveys, but we could not find an open-source web-based survey applications suited for respondent customized stated choice games. Therefore, a primary goal of this project was to create a web-based survey framework that could perform stated-choice experiments. We were looking for a survey framework with the following properties:

- Reusable
- Flexible survey design
- Simple survey creation tool
- Can perform RP and SP surveys
- Can customize stated-choice games based on the user's responses
- Both web-based and in-person (computer-assisted) collection possible
- Stores responses in a database

For this project, JULIE was created to provide a platform for creating web-based travel surveys. JULIE depends on the following:

- Ruby, a programming language
- Rails, a web-application framework
- SQLite, a database
- JULIA, a domain-specific language for creating surveys

In this section, the Rails web application framework will be briefly described. Then the JULIE framework will be described with details related to the controllers, model, and views. Finally, the administration of the survey via JULIE will be discussed.

5.1 Ruby on Rails

JULIE was built using the Ruby programming language. Appearing in 1995, Ruby is a dynamic, reflective, object-oriented programming language. Ruby is the backbone of JULIE and provides it with the capabilities it needs to perform calculations and conditional logic in order to create and customize surveys to different purposes and different respondents. Ruby was chosen because it:

- *Has a simple and flexible syntax.* This allows the language to be easier to read than other programming languages and also lends itself well to be the foundation of domain specific languages (DSLs). A DSL will be helpful for survey creation as it allows a format for creating survey questioning and logic in an easy to read format. A DSL will also allow users to create surveys without knowledge of Ruby and the underlying framework of the application.
- *Has a large class library.* Ruby has a sufficient library to do the important tasks needed for this project, such as database operations, HTML syntax, and web application functions.
- *Is free and open-source.* This ensures that JULIE is not limited by proprietary licenses.
- *Has an industry recognized open-source web application framework.* Rails is built on Ruby and is well-known in web development for its conventional style, ease of use, and quick development.

Rails provides the framework for the web application portion of JULIE. The Rails framework is based around the Model-View-Controller (MVC) design pattern. In MVC, a model performs the logic and calculations for an application; it represents the data and makes changes to it. The view provides a way to interact with the model;

text interfaces and graphical user interfaces are examples of views. The controller receives input from the view and notifies the model that changes need to be made; it then receives changes from the model and updates the view to comply with those changes. In Julie, the model and controller are based in Ruby while the view is based in HTML with embedded Ruby (eRuby).

Rails projects are made up of the following primary components:

- */app* – This is where the MVC coding for the application is stored. It holds the model, view, and controller for JULIE and will be described in further detail in the following sections.
- */config* – This contains the code for configuring the application. It determines which databases to use and the routing for incoming web requests.
- */db* – This contains the database files (SQLite databases for JULIE) for the application.
- */doc* – This contains documentation for the code. Rails can automatically generate documentation for code written in the /app folder
- */lib* – This stores the additional libraries, if any, needed to run a Rails application
- */log* – Error logs are stored in this location.
- */public* – Any files which are accessible to the public on your server are placed in this folder. Typical examples include images and stylesheets.
- */script* – This is where the scripts for launching the application are located.

5.2 JULIE Application

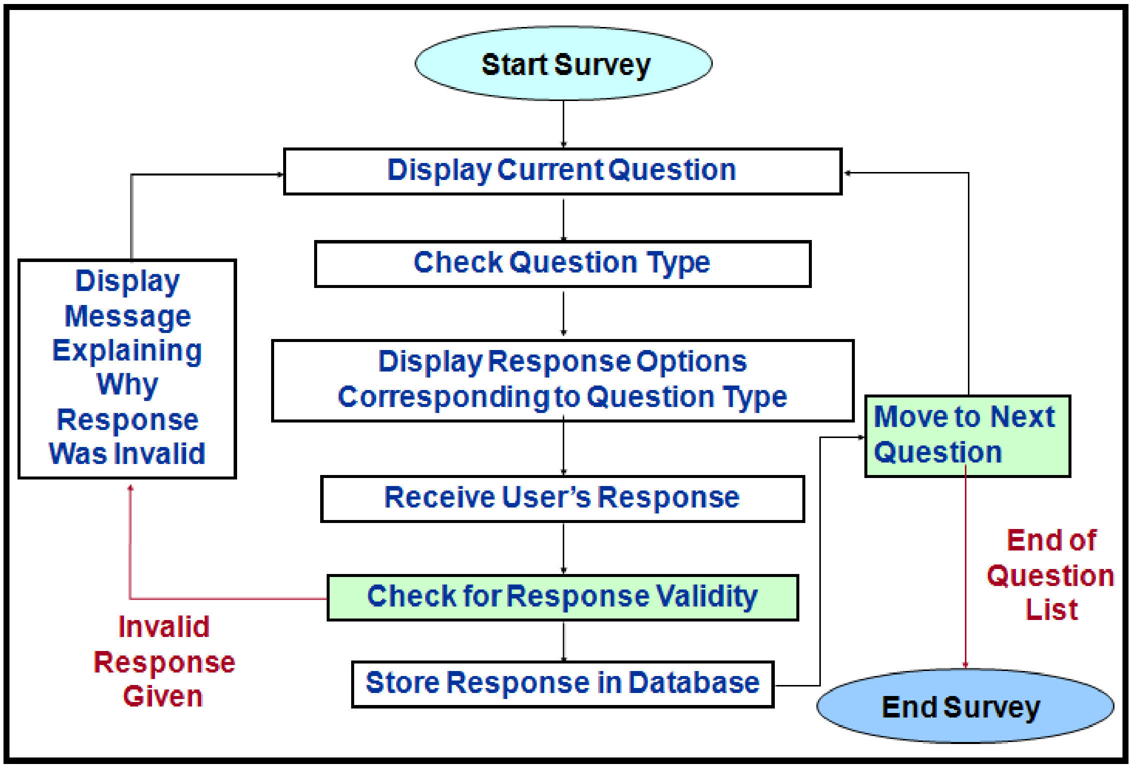


Figure 7 JULIE Flowchart

The JULIE framework provides a system for creating surveys, displaying questions, controlling question flow, and storing responses. Figure 7 provides a simplified view of the framework. The basic premise is that JULIE displays a sequence of questions to the user, records his responses, and ensures that the responses are in the expected format. This process is essential as the surveys are designed to be self-administered online, an environment where the researcher cannot help the respondent. Using this flowchart as a guide, JULIE is built around the Rails convention of Model-View-Controller (MVC) (see Figure 8). Therefore JULIE is made up of three parts:

- *Controller.* The controller interfaces between the model and the view. In JULIE, the controller is responsible for providing questions from the model to the view; taking responses from the view and storing them in the model; and ensuring the user is at the proper question in the survey.

- *Model.* The model contains the data of the application. In JULIE, the model contains the survey's questions and question list and the database structure.
- *View.* The view interfaces with the respondent via a web browser. The view is responsible for displaying questions to the respondent and receiving their responses.

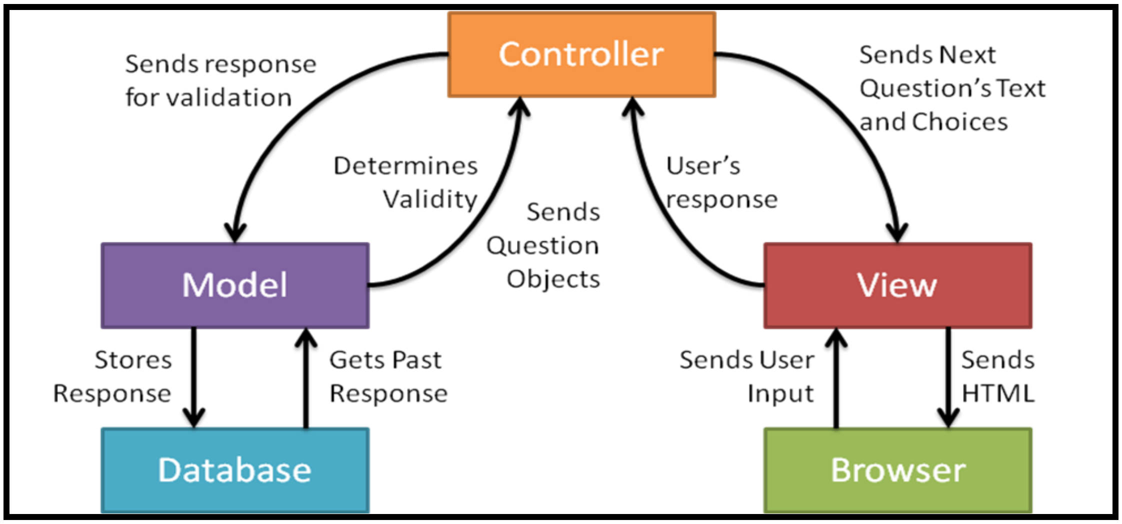


Figure 8 MVC Framework

5.3 Controller

The controller is primarily made up of the *session* and the three methods: *survey, scenario,* and *check.* The session stores small amounts of data that can persist between user requests (actions by the user to change or request data from the model). The *survey* controller provides the view with the components needed to display most question types, such as multiple choice and open-ended. The *scenario* controller provides the view with the components needed to display stated choice experiments. The *check* method receives responses from the view, verifies the answer provided is acceptable, and then proceeds to direct the controller to provide the view with the next question.

5.3.1 Controller – Session

The session is a hash-like structure that is created for each user. It stores small amounts of information that persist between user requests (between accesses to different pages). For JULIE, session data is stored in a database on the server rather than on the client's computer. In JULIE, the session is used to keep track of the user's id, question number, and question sequence; for storing calculated values; and for describing invalid input.

The following summarizes the parts of the session:

- *User ID*. Each user is given a sequential id which is used to connect the user's responses with an entry in the database.
- *Question Number*. The session keeps track of the number of questions the user has actually seen in the survey as well as the current question's position in the list of questions (*Survey* object).
- *Question Sequence*. The question sequence is an ordered list of the questions the user has already seen. This list is important whenever a user needs to go back during the survey since the question sequence is not always sequential (branching may occur).
- *Storing Calculated Values*. Sometimes calculations are performed which are important for showing the respondent some customized values. These values are calculated in the controller then stored in the session to be used at a later time.
- *Invalid Responses*. The *flash* temporarily stores an explanation of why a user's input is invalid. The *flash* is a portion of the *session* that only lives through one request to the server.

5.3.2 Controller – Survey

The *survey* method of the controller is invoked during the showing of all questions except choice experiments (or scenarios). It provides information to display in the view.

The *survey* method begins by loading the question list and finding the current question index (received from the *session*). *Survey* then checks whether the question belongs to a choice experiment, if so it then redirects to the *scenario* controller. *Survey* proceeds to load the essential components of the question: question text and type.

Question texts are allowed to have modifications that load variables from the *session* or the database. *Survey* performs the replacement operation to replaces blocks of text (keywords and phrases) with the appropriate variable information.

The question type determines what additional information is needed for the view to properly display the question. For multiple choice questions, answer options (choices) are given to the view. For calculations, *survey* performs the calculations, loads the variables to the session, and then proceeds to the *check* controller.

Any messages located in the *flash* portion of the *session* are sent to the view.

5.3.3 Controller – Scenario

The *scenario* method of the controller is invoked during the showing of choice experiments. It provides information to the view to aid in displaying scenarios.

The *scenario* method begins by loading the question list and finding the current question index (received from the *session*). *Scenario* then checks whether the question belongs to a choice experiment, if not then it redirects to the *survey* controller.

Scenario proceeds to load the question object and obtains the question text, choice options, alternatives shown, attribute labels, and scenario design. The question text contains both pre-table and post-table text options. To provide the view with the table needed to display the scenario to users, *scenario* gives the view the list of alternatives to show (the columns to display). The attribute labels, if provided, are given to denote each row of the table. The scenario design, which is a collection of variable levels for each alternative, is received from the model and given to the view. Additionally, the list of choice options is provided to the view.

If any messages are in the *flash* portion of the *session*, these are sent to the view.

5.3.4 Controller – Check

The *check* method is an important connection between the view and the model. It receives responses from the view (user input), checks the validity of the input, and redirects the survey execution to the next appropriate question.

First, *check* receives user input from the *session*. It then feeds this input into the question object for the current question and receives confirmation of whether the input is valid or not. If the input is invalid, control is redirected to the appropriate method to redisplay the question and a message explaining why the input is invalid is placed in the *flash*. Otherwise, for valid input, the response is stored in the database in a position corresponding to the user's id and the question name. The current question index is then added to the *session* (question sequence) and the survey execution proceeds to the next question.

5.4 Model

The model contains and manipulates the data of the survey. The model is made up of *question objects, choice experiments,* the *survey*, the *JULIA interpreter,* and a *database*. The *survey* is written using the JULIA domain specific language. The JULIA interpreter reads a survey file and translates it into a list of question objects and choice experiments. These *question objects* are Ruby data structures which represent the various question types which JULIE is capable of creating and displaying. Responses to the questions are stored in the *database*.

5.4.1 Model – Questions

Since object-oriented principles were used in the design of JULIE, questions are represented as objects through a series of classes. To take advantage of the inheritance and duck typing features of Ruby, an inheritance hierarchy was created to represent different question types. The advantage of this approach is that, since many question types share features, an inheritance structure allows for greater code reuse, easier debugging, and eases extensibility of the JULIE framework.

Figure 9 describes the inheritance structure for *Question* classes. Descendants of classes progress from left to right (i.e. the parent of an object is to the left of that object in the tree). The boxes with black text and white backgrounds represent classes that are used for creating questions that are displayed to respondents. The boxes with white text and black backgrounds represent objects which do not display questions but perform functions that affect question flow or modify parts of the *Session* controller and the database. The box with a dotted outline represents the *Scenario* class which is used in creating stated choice games.

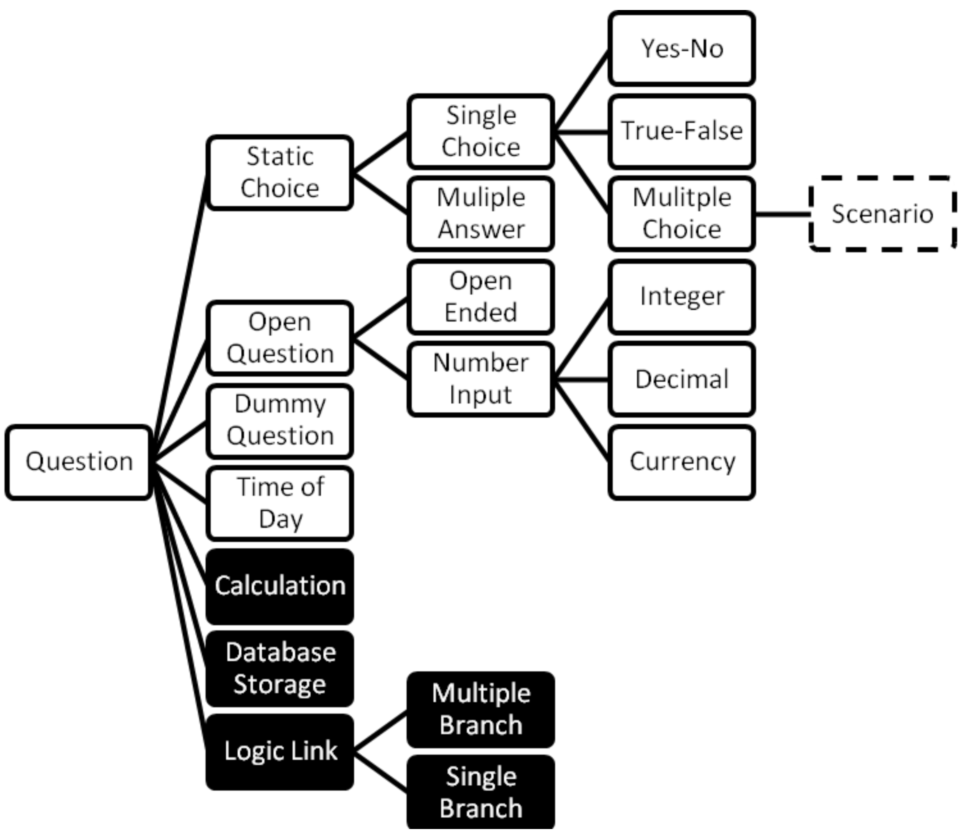


Figure 9 Question Class Inheritance Structure

The following list describes each class in the white boxes and its functionality:

- *Question.* The parent at the top of the tree, the *Question* class does not have full functionality but provides the "base skeleton" for all its descendants. *Question* creates the following state: question name and question text. The question name is an identifier that provides a potentially unique id for a question. The question name is also used as a column header in the database to store any responses to questions of the same name. The question text is the content to show the respondent when they view the question. The question text allows for the use of HTML in question text as well. The *Question* class also sets up a base for checking for validity. The only functionality for this is to check for when no answer is provided.
    - *Static Choice.* The *Static Choice* class is similar to an abstract class. It is the parent of all questions which provide choice options to respondents. This class adds the capability to add choice options to the question.
        - *Single Choice.* This class does not expand upon the capabilities of *Static Choice.* It just serves as a parent to some specialized versions of single choice questions. Additionally, this allows the view to know to use radio buttons when displaying choice options, so that only one option can be chosen.
            - *Yes – No.* This is a simplified single choice question where the only options are "Yes" and "No." This is a common question type so it was given its own class to simplify survey creation.
            - *True – False.* Just like the *Yes-No* object type, this question only provides the options of "True" and "False."
            - *Multiple Choice.* This question just inherits all functionality from *Single Choice* and does not expand upon it. It was just created to make the inheritance structure more symmetric (*Single Choice* appears more abstract).
        - *Multiple Answer.* This class does not expand upon the capabilities of *Static Choice.* When objects of this class

checks for response validity, it receives an array of choices the respondent made. The object then checks that each element in the array is a valid choice. Additionally, this allows the view to know to use check boxes when displaying choice options, so that zero or more options can be chosen.

- *Open Question.* This class does not expand upon the capabilities of *Question*. It serves as an abstraction for questions that want input from the keyboard.
    - *Open Ended.* An *Open Ended* question allows for any text response, except for an empty string, to be submitted.
    - *Number Input.* This question is an abstraction for its children classes.
        - *Integer.* This class creates objects which only take integers as input.
        - *Decimal.* This class creates objects which only take integers or rational numbers as input.
        - *Currency.* This class creates objects which only take integers or rational numbers with two decimal digits of input. The regular expression that describes this input is: `/^-?\s*\d+(.\d+)?\s*$/` .
- *Dummy Question.* A *Dummy* question provides the same functionality as a *Question*. *Dummy* questions are typically used to provide instruction or inform the respondent. *Dummy* questions do not expect any input from the respondent.
- *Time of Day.* This class provides objects which expect input in the form of minutes after midnight.

The objects in the black boxes (*Calculation*, *Database Storage*, *Logic Link*) are described in Section 5.4.3. The *Scenario* object is described in Section 5.4.2.

5.4.2 Model – Choice Experiments

In JULIE, stated choice games are represented using the *ChoiceExperiment* class. *ChoiceExperiment* objects have the following state:

- *Name.* A unique identifier for a particular *ChoiceExperiment*.
- *Pre-table Text.* Text to display to the respondent before the scenario table.
- *After-table Text.* Text to display after the scenario table.
- *Alternatives.* A list of the alternatives to display in the scenario table. Each table has a column for each alternative in the list. Note that alternatives are different than the choice set (see Figure 10).
- *Choice Set.* The list of choices the respondent can make for the scenario shown (see Figure 10).
- *Variables/Attributes.* A hash in which the keys are the attribute names and the values for each key is an array of attribute levels (see Figure 10).
- *Experimental Design.* A two-dimensional array which represents individual scenario designs. These designs are the indices of the levels to display for an alternative.
- *Number of Scenarios.* The number of choice games to display to respondents based on the alternative and attributes of this choice experiment.

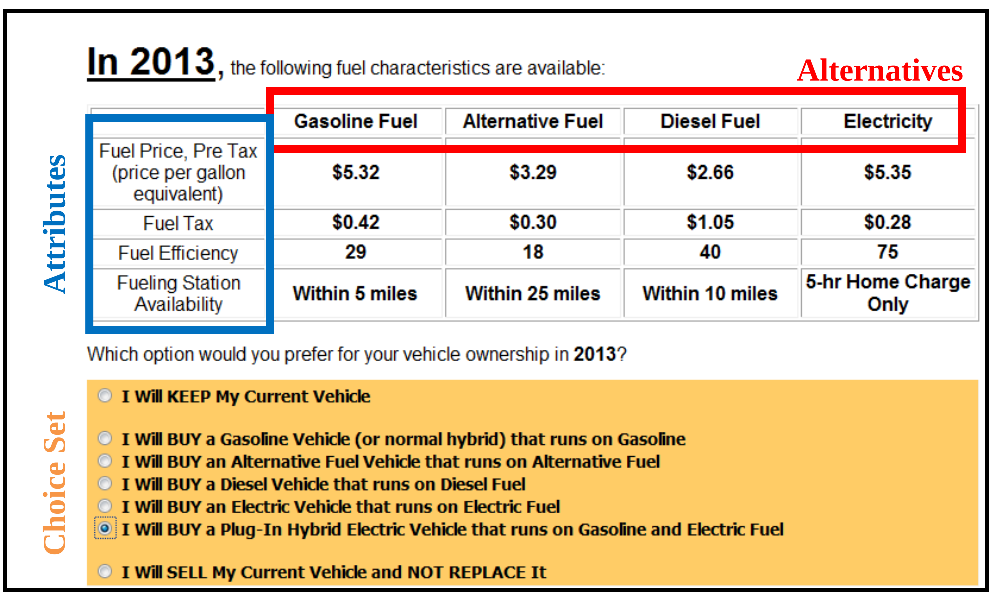


Figure 10 Scenario Design

ChoiceExperiment objects allow survey designers to create the state of an experiment. This allows JULIE to generate scenarios to display to respondents. When generating designs, JULIE chooses a random design from the experimental design array for each alternative.

As described in the last section, the *Scenario* class is a question type associated with choice experiments. A *Scenario* object contains a reference to a *ChoiceExperiment*. *Scenario* objects receive random designs from the *ChoiceExperiment* associated with it and provide a table design to the controller (which the controller sends to the view).

5.4.3 Model – Other Classes

Additionally, there are question classes which facilitate direct database insertions, various calculations, and question order logic.

The *Database Storage* class just provides the functionality to take a value from either the *Session* hash or a value provided by the survey designer and place it in the database. This value is placed in a column corresponding to the name of this object.

The *Calculation* class provides a wrapper for the execution of various calculations at a particular point during a respondent's survey progression. Objects of this class are typically used to perform operations on respondent-specific data. *Calculation* objects have a list of commands. These commands are various functions which modify values and store them in the *Session* hash. The *Calculation* class has an *execute()* method which performs each command in sequence when called.

Commands are functions or methods with a variable and operand(s). The variable is the name of the location in the *Session* hash to store the result of the command. The operands are the inputs into the function, if needed. The *Calculation* class has the following commands:

- *Add, Subtract, Multiply, Divide.* Basic arithmetic functions between two or more values. Values must be integers or floats and can be defined by the survey designer or be from the *Session* hash.
- *RandomNumber(n).* Stores a random number between 0 and *n*-1, where *n* is the operand.
- *ConvertToInteger(x), ConvertToFloat(x).* Converts values into integers or floats for display and calculation purposes.
- *Round(x ,n).* Rounds a number *x* to the closest *n*th.
- *ConvertMins(x).* Converts a time in the form of minutes after midnight into *H:MM AM/PM* format.
- *ConvertCurrency(x)*. Converts a float or integer into currency format, *D:CC.*
- *Decimal(f, n).* Truncates a floating point number *f* to the precision given by *n*.
- *Conditional(x, y).* Creates a series of "if equal to" statements based around the value of *x* and a hash *y* of conditionals.
- *Range(x, y).* Creates a switch-like statement in which values of *x* between different ranges in the hash *y* get stored as particular values.
- *DatabaseVariable(x).* Stores the value of the entry in column *x* of the database in the *Session* hash.

- *SetValueInDatabase(x, y).* Stores the value *x* in the database in a column named *y*.

To control the flow of question execution in a survey, the *Logic Link* class and its descendents provide techniques to change question flow. The *Logic Link* class is an abstract class which sets up the functionality of question logic objects. The *next_question()* method must be implemented by all descendants of this class; it returns the name of the next question to progress to.

The *Single Branch* class provides links which will always go to a particular question. For example, let a survey have the following question list: A→L(D)→B→C→D→E, where A, B, C, D, and E are questions and L(D) is a *Single Branch* object with destination D. After a respondent completes question A, L will cause the survey to progress to question D, thus skipping questions B and C.

The *Multiple Branch* class provides links which will allow the question sequence to change depending on the response to a previous question. For example, if a question asks if someone works, then a *Multiple Branch* link could send respondents with a job to questions about their commute and for other respondents it could send them to questions about their job search prospects.

5.4.4 Model – Survey

A *Survey* object is a collection of questions and choice experiments which represents an actual survey. The list of questions is a sequence of different question objects.

Survey execution begins with the first question in this list and progress sequentially, unless a *Logic Link* is encountered. *Scenario* questions in this list refer to *ChoiceExperiment* objects stored in the *Survey*.

5.4.5 Model – JULIA DSL

JULIA intends to provide a readable format for survey creation. JULIA is an internal domain specific language (DSL) for the creation of surveys in JULIE. Because it is an internal DSL, writing code in JULIA is essentially the same as writing Ruby code; but Ruby is "hidden" by the use of method names which make survey creation visually intuitive.

Writing surveys via JULIA is a sequential process. Through the use of methods for each particular question class, creating questions sets scope (dynamic scope). After a question is created, all methods after it, except methods that create questions, refer to that question.

The following is an example of a *Yes–No* question in JULIA:

```
yesNo "HEAD_OF_HOUSEHOLD"
Q "Do you consider yourself the head of the household?"
```

"yesNo" informs the interpreter than a *Yes–No* question is being created with the name *HEAD_OF_HOUSEHOLD.* The second line of the example sets the question text for *HEAD_OF_HOUSEHOLD.*

The following is an example of a M*ultiple Choice* question in JULIA:

```
multipleChoice "HOME_TYPE"
Q "Which of the following best describes your home?"
choice 0, "College Dorm"
choice 1, "Apartment"
choice 2, "Condominium"
choice 3, "Townhouse"
choice 4, "Single-Family Home"
choice 5, "Other"
```

Like the question before, “multipleChoice” informs the interpreter that a *Multiple Choice* question is being created with name *HOME_TYPE*. The third line of the example sets the first choice option with a value of *0* and display text “College Dorm.”

The following is an example of an *Integer* question in JULIA:

```
integer "AGE"
Q "What is your age?"
bounds 1, 130
```

The third line of this example sets a validity check for question *AGE.* Only values between 1 and 130 inclusive are valid.

The following is an example of the basic setup for a choice experiment:

```
createChoiceGame "FLIGHT_GAME"
scenarioQuestion "Choose one of the following flights:"

defineAlternative "Flight A"
defineAlternative "Flight B"

defineChoice “I will take Flight A”
defineChoice “I will take Flight B”
defineChoice “I will not fly”

numberOfScenarios 9
```

This example creates a choice experiment with name *FLIGHT_GAME*. Lines 3 and 4 create the list of alternatives: “Flight A” and “Flight B.” After this is the list of choices to display to respondents. The last line of the example notifies the interpreter to create nine *Scenario* questions corresponding to this choice experiment.

The following is an example of creating attribute levels for a choice experiment:

```
createVariable "Return Fare", 4
level 0, 300
text "Return fare of $300"
level 1, 400
text "Return fare of $400"
level 2, 500
text "Return fare of $500"
level 3, 600
text "Return fare of $600"
```

The first line creates an attribute with label "Return Fare" which has four levels of variation. The first level of variation (see lines 2 and 3) is indexed to *0* and given a value of 300. The display text for this level (shown in the scenario table) is given in the third line. The remaining code creates the other three levels for the "Return Fare" attribute.

5.4.6 Model – JULIA Interpreter

The interpreter provides the method definition for the JULIA DSL and reads a text file representing a survey and converts it to a question list (or *Survey* object). The method definitions in the interpreter provide the level of abstraction for JULIA. These are essentially a list of first words that can be used on any line of a survey text file. Each method performs functions on a *Survey* object, either modifying the last question or choice experiment added to it or creating a new question or choice experiment.

5.4.7 Model – Database

Responses from the controller are stored in a SQLite database. SQLite was chosen because it is easy to maintain, can handle small sized databases, and contains all data in a single file. The database is a simple design with one table. Each respondent is stored in a row of the table. The table stores the responses, or mappings of responses, for each respondent as they are inputted into the survey. The table columns correspond to questions in the survey.

5.5 View

The view is written in HTML with embedded Ruby. The view visually provides the user with a place to see and respond to questions. The view primarily consists of two parts: the *survey* and *scenario* views. These views have corresponding controllers with the same name. The *survey* view displays questions corresponding to all question types except choice experiments. The *scenario* view displays the scenarios from the stated choice experiments.

The view can freely allow the use of HTML in the question text and choices for *Static Choice* questions. This allows flexibility in display, which means that not only can text be displayed but also pictures and other embedded objects (e.g. interactive maps).

5.5.1 Survey View

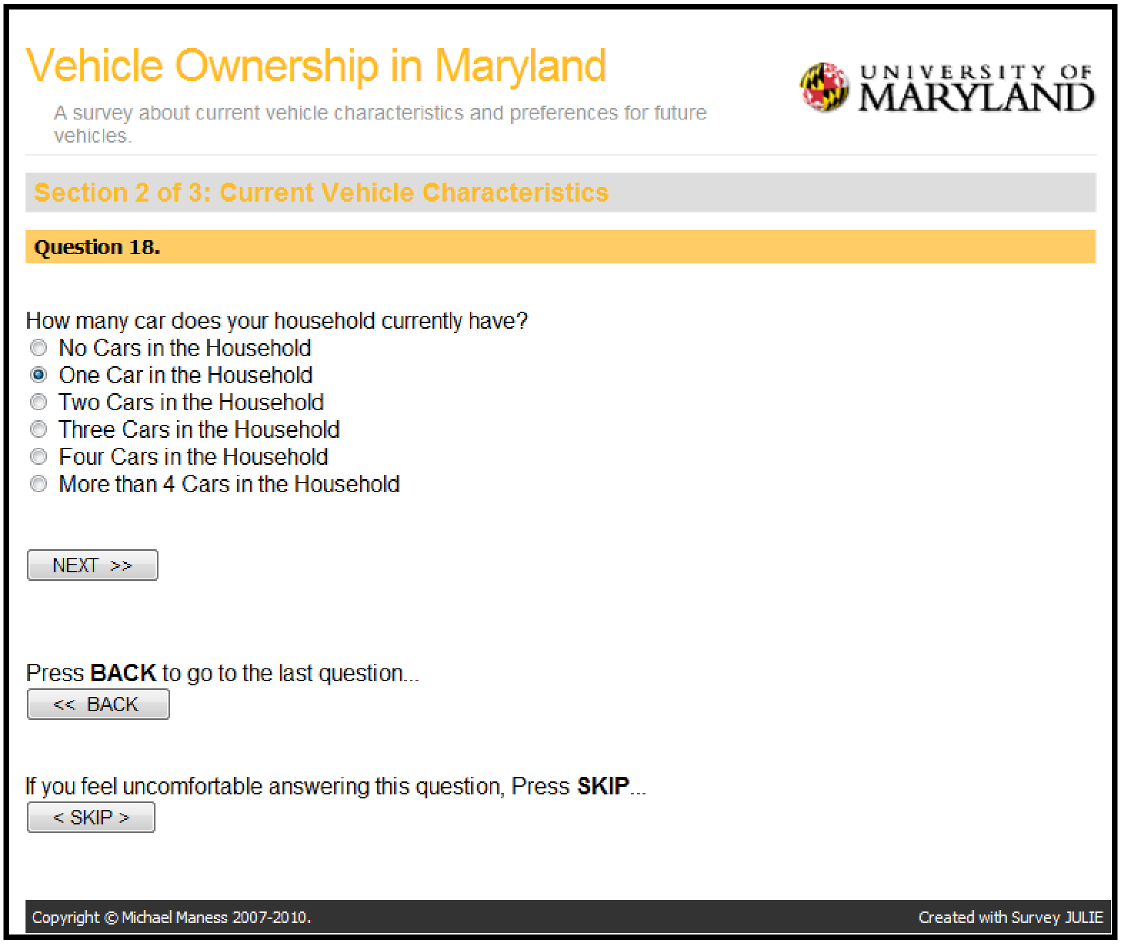


Figure 11 Example of the Survey View

For non-scenario questions, the general view format (see Figure 11) includes a header at the top of the page with the survey's title and a brief description. Below this, the question number (question count) and the section header are displayed. The bottom of the page includes buttons for going to the next question, returning to the previous question, and if allowed, an option to skip the current question.

For *Multiple Choice* questions, radio buttons are displayed adjacent to the choice list. For *Multiple Response* questions, check boxes are displayed adjacent to the choice list. For *Time of Day* questions, drop-down lists for hour, minute, and AM/PM are provided. All other question types use a text box for input.

5.5.2 Scenario View

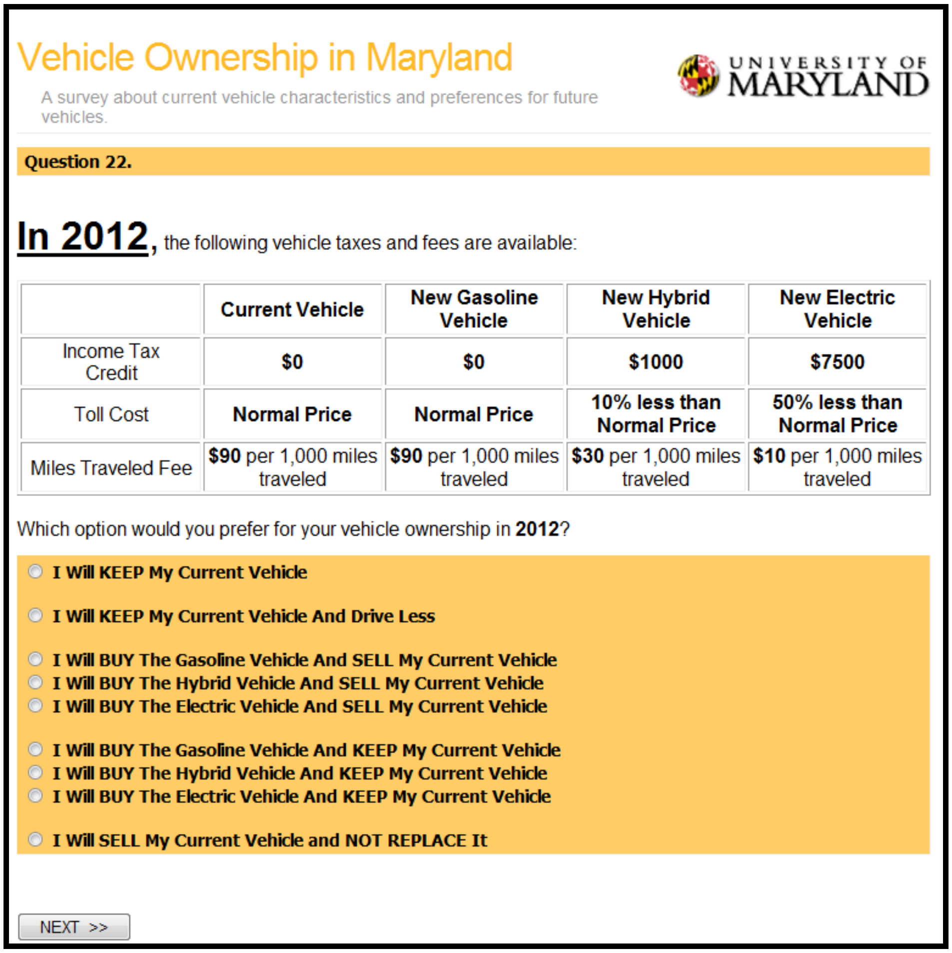


Figure 12 Example of the Scenario View

The scenario view is similar to the view provided for *Multiple Choice* questions in the *Survey* view. Under the section header, respondents are shown information prior to the table; this text typically describes the table below. JULIE displays a table with column headers corresponding to alternatives and row headers corresponding to attributes. This table contains the scenario design given to the view from the controller.

Following the table is more text, typically asking the respondent to make a choice. Below that, the choice set is displayed with radio buttons beside each choice option. Figure 12 provides an example of the Scenario view.

5.6 JULIE Survey Administration

JULIE can work in both online and offline modes. JULIE was primarily designed to be a web survey collection tool. It is designed for low and medium demand websites and is flexible enough to provide basic question displays as well as more complex visual designs (depending on the HTML skills of the designer). In offline mode, it provides a browser application for performing computer-assisted interviewing: computer assisted self interviews (CASI), computer assisted personal interviews (CAPI) and computer assisted telephone interviews (CATI).

Chapter 6: Results – Descriptive Statistics

Survey data was collected throughout September and October of 2010. The CASI survey was performed during the weekend of September 3rd. The web survey was performed from September 10th through October 31st. There was a 94% completion rate with a sample size collected of 141 completed surveys and 13 incomplete surveys.

6.1 Socioeconomics Results

Socioeconomic data was collected for the respondent's gender, age, education, household position, occupation, and commute time; and the household's income, age distribution, worker quantity, location, and building type.

Gender. 52% of respondents were male.

Table 9 Gender of Respondents

	Number of Respondents	Percentage
Male	73	52%
Female	68	48%
No Response	1	0%

Age. Respondents' ages were distributed with an average age of 43 and median age of 41. The youngest respondent was 18 and the oldest respondent was 83.

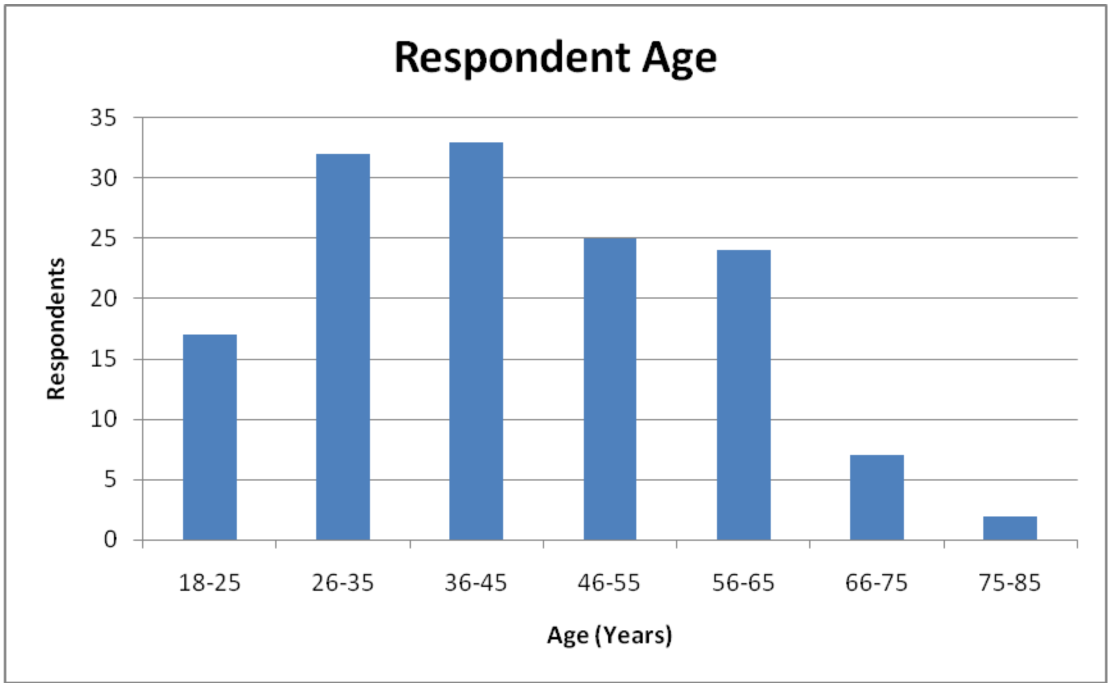


Figure 13 Respondent Age Distribution

Education. The highest education level of respondents was generally college-based. 77 respondents had graduate or professional degrees, 30 respondents had bachelor degrees, and 7 respondents had associate degrees. Of the remaining respondents, 1 did not have a high school diploma, 12 respondents had high school diplomas, and 14 respondents had some college coursework.

Table 10 Education Level

	Number of Respondents	Percent of Respondents
Less than High School	1	1%
High School Diploma or Equivalent	12	9%
Some College	14	10%
Associate	7	5%
Bachelor Degree	30	21%
Graduate or Professional Degree	77	55%

Head of Household. 61% of respondents were the head of their household.

Table 11. Head of Household

	Number of Respondents	Percentage
Head of Household	87	62%
Other Household Member	53	38%
No Response	1	0%

Income. The income distribution was generally above the Maryland median. 22% of households had incomes above $150,000. 21% of household had incomes between $100,000 and $149,999. 18% of households had incomes between $75,000 and $99,999. 12% of households had incomes between $50,000 and $74,999. 15% of households had incomes between $25,000 and $49,999. 8% of households had incomes less than $25,000 with the remaining households (4%) refusing to answer the question.

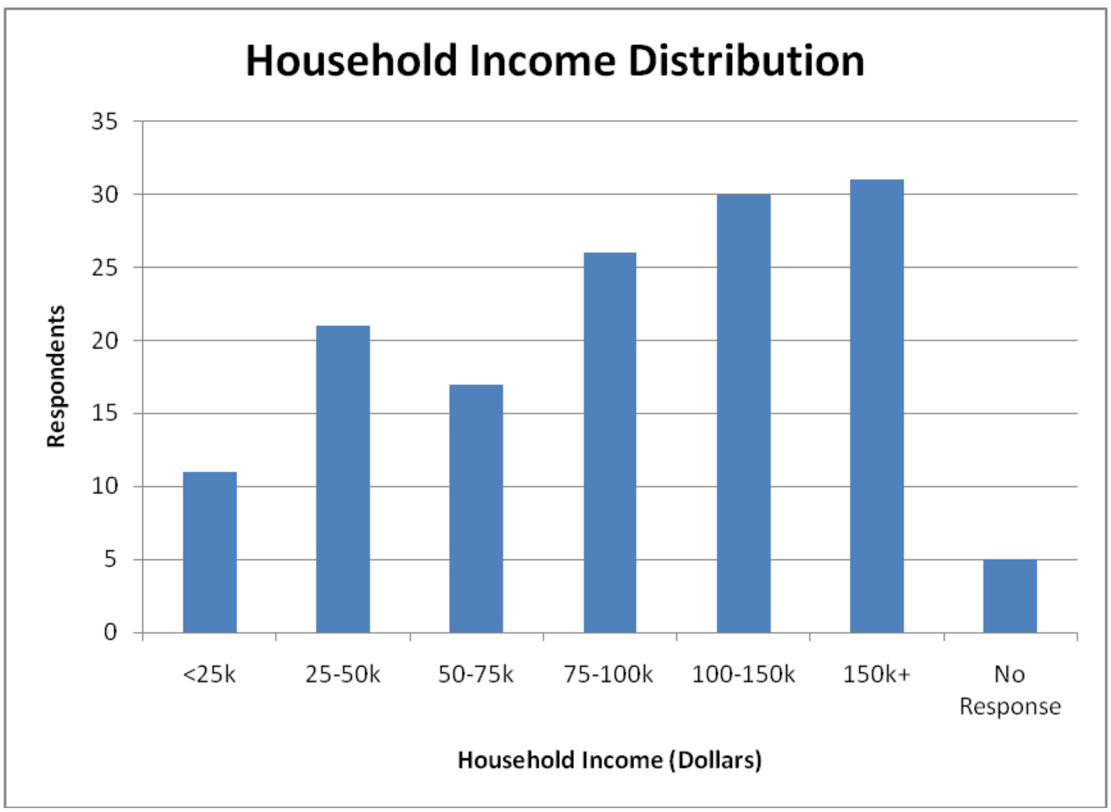


Figure 14 Household Income Distribution

Household Age Distribution. The average household size was 2.74 people with 2.07 adults per household, 0.45 children under 12 years old and 0.22 adolescents. The median household size was 2.00.

Table 12 Household Age Distribution

Number of Households with:	Children	Adolescents	Adults
0	102	122	0
1	20	12	35
2	17	5	74
3	0	1	22
4	1	0	7
5	1	0	3
6	0	1	0

Workers. The average number of workers per household was 1.63 with a median number of workers equal to 2.00. One household chose not to respond.

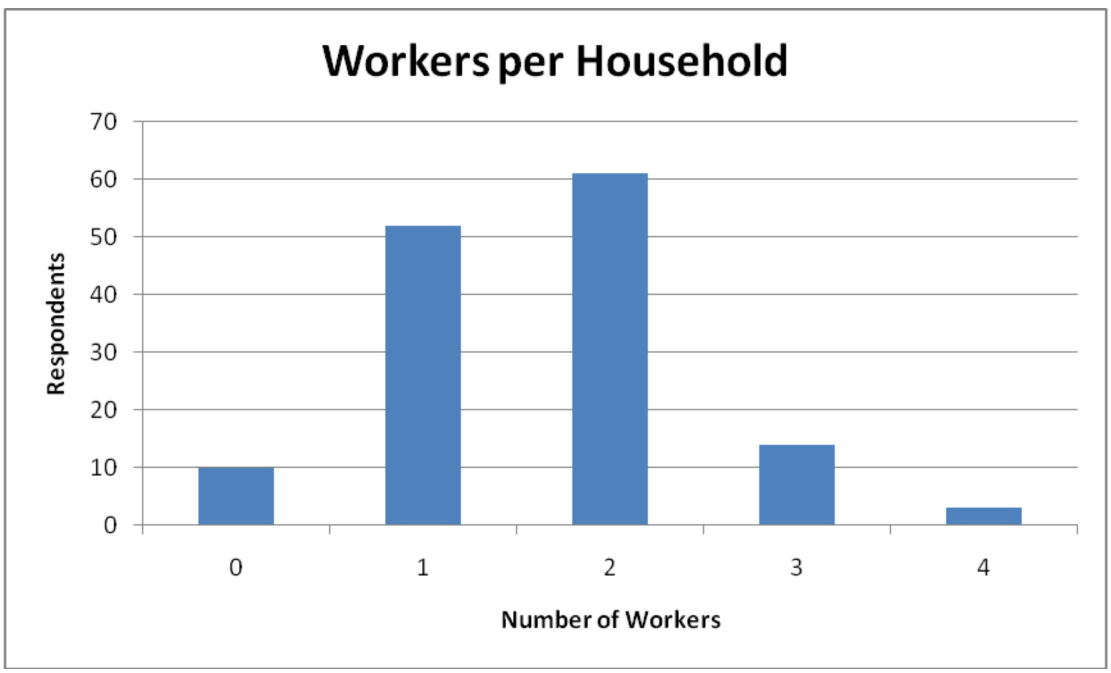


Figure 15 Workers per household

Location. The majority of respondents (138) lived in the state of Maryland with one respondent each from Virginia, Washington, D.C. and "Other." The most common zip codes of respondents were 20770 (Greenbelt), 20850 (Rockville), 21213 (Baltimore), and 20877 (Gaithersburg). By county, 48% of all households were located in Montgomery County, 25% in Prince George's County, 9% in Anne Arundel County, 6% in Baltimore City, 5% in Howard County, and the remainder from Kent and Frederick Counties and outside of Maryland. This corresponds to an eligible respondent rate of 93%. Appendix F shows the distribution of locations on a map.

Two respondents did not respond to the zip code question and two respondents provided invalid responses.

Table 13 Households by County

County	Households	Percentage
Prince Georges	35	24.82%
Montgomery	67	47.52%
Baltimore City	9	6.38%
Howard	7	4.96%
Anne Arundel	13	9.22%
Kent	2	1.42%
Frederick	1	0.71%

Home Type. A majority of respondents lived in single-family dwellings: 62 respondents lived in detached houses and 45 respondents lived in townhouses or rowhouses. Of the respondents who lived in apartment-style housing, 21 described their home as an apartment, 9 lived in condominiums, and 1 lived in student housing. One household did not respond to the question.

Table 14 Households by Home Type

House Type	Households	Percentage
Dorm/Student Housing	1	1%
Apartment	21	15%
Condo	9	6%
Townhouse	43	30%
Rowhouse	2	1%
Detached Home	62	44%
Other	2	1%
No Response	1	1%

Work Status. The work statuses of respondents were generally full-time (104 respondents). Eight respondents described themselves as part-time workers, six were homemakers, five were students, twelve were retired, and three were described as "Other." Only three described themselves as "looking for work" and it is not clear whether the people in the "Other" category were unemployed or not.

Table 15 Respondent Work Status

Work Status	Respondents	Percentage
Full Time	104	74%
Part Time	8	6%
Looking for Work	3	2%
Homemaker	6	4%
Student	5	4%
Retired	12	9%
Other	3	2%

Commute Time. The round-trip commute time of working respondents (full-time, part-time, and students) was 30 minutes on average. The median commute time was 24 minutes with a maximum commute of 130 minutes. 39% of commuters had commute times of 15 minutes or less, while 25% had commute times between 16 and 30 minutes. 25% of commuters had commute time between 31 and 60 minutes. 8%

of commuters had round-trip commutes of over an hour. One household chose not to respond.

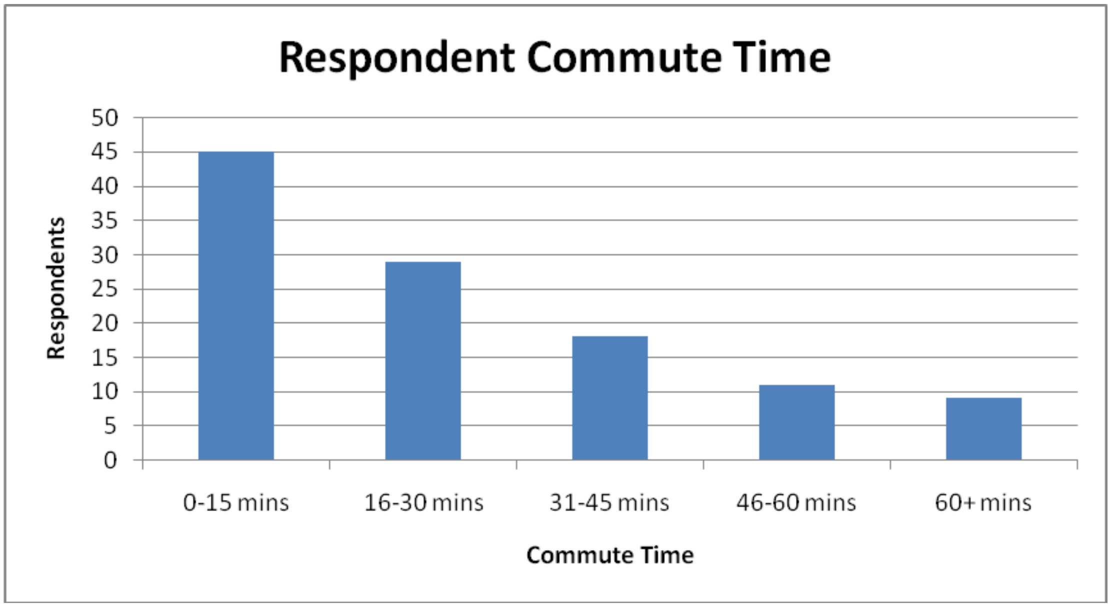


Figure 16 Commute Time

Driver's License. 96% of respondents had driver's licenses.

Table 16 Driver's License Status

	Respondents	Percentage
License	136	96%
No License	5	4%

Home Parking. Home parking varied fairly evenly. 20% of respondents have personal garages, 28% have driveways, 20% park on-street, and 23% park in outdoor lots.

Table 17 Home Parking Status

Parking Type	Households	Percentage
Personal Garage	28	20%
Personal Driveway	39	28%
On-street	28	20%
Outdoor Parking Lot	33	23%
Parking Garage	3	2%
Other	2	1%
No Car	7	5%

Work Parking. 87% of workers said that parking was available at their workplace. The median parking cost was $0 with 75 out of 100 workers stating that they had free work parking. Of the workplaces with parking costs, the average parking cost was $100 per month. The highest parking cost stated was $300.

Two respondents skipped the *Parking Cost per Month* question.

Table 18 Work Parking Availability

Work Parking Available	Respondents	Percentage of Workers
Yes	102	87%
No	15	13%
Not Working	24	--

Table 19 Work Parking Costs

Cost	Respondents
Free	75
$1 - $50	9
$51 - $100	5
$101 - $150	6
$151 - $200	3
$201 - $250	1
$251 - $300	1
No Response	2

6.2 Current Vehicle Characteristics

In the RP portion of the survey, respondents were asked about their household vehicles and the characteristics of their primary vehicles.

Vehicles Per Household. There was an average household vehicle quantity of 1.87 vehicles and a median of 2.00 vehicles. 35% of household had one vehicle, 34% had two vehicles, and 21% had three vehicles.

Table 20 Vehicles per Household

	Cars per Household	Households	Percentage
0	None	7	5%
1	One	50	35%
2	Two	48	34%
3	Three	29	21%
4	Four	5	4%
5+	More than Four	2	1%

Primary Vehicle Make and Model. Of the 134 households with at least one vehicle, only 11 respondents did not provide a model name and 3 respondents provided a model name without corresponding make. This is a 90% appropriate answer rate. This may indicate that using a database of make and models could be a reasonable investment to reduce the number of questions in the survey and increase the quality of primary vehicle measurements.

A qualitative assessment of the responses from other vehicles show a decrease in the quality of responses as a household has more vehicles. It appears that recall is more difficult for vehicles that respondents do not often use.

Primary Vehicle Size. 38% of respondents used a compact/small car as their primary vehicle. 24% drove a mid-size car and 10% drove a large car. 16% of households used a pickup truck as a primary vehicle. Of the remaining household, 6% drove a van as primary transport and 1% of households used a sports utility vehicle (SUV) as a primary vehicle.

Table 21 Primary Vehicle Size

Vehicle Size	Households	Percentage
Compact Car	54	38%
Mid-Size Car	34	24%
Large Car	14	10%
Van	9	6%
SUV	1	1%
Pickup Truck	22	16%
No Car	7	5%

Primary Vehicle Age. The average age of primary vehicles were 6.37 years with a median age of 6.00 years. 36% of primary vehicles were less than five years old, 44% were six to ten years old, and 20% were over ten years old. Two households skipped this question.

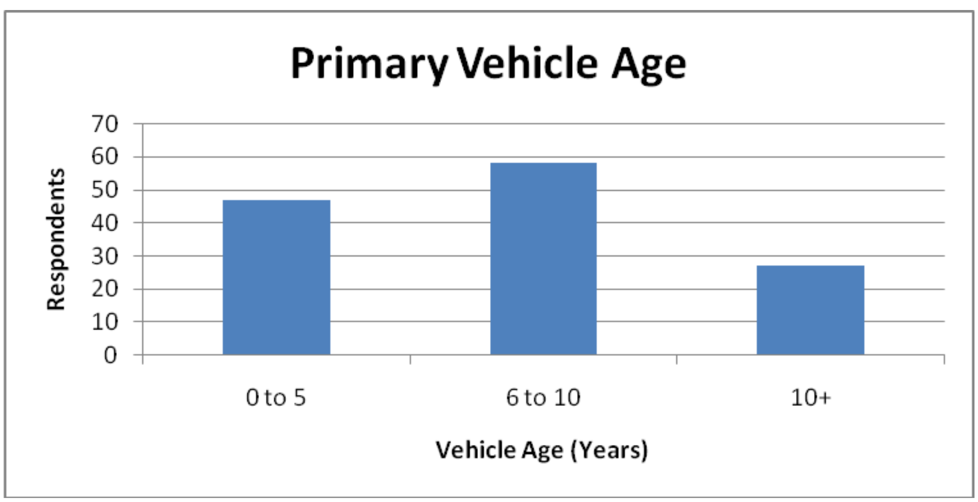


Figure 17 Primary Vehicle Age

Primary Vehicle Mileage. The average annual mileage was about 15,000 miles. The median mileage was 10,000 miles. Twenty-five respondents (18%) did not know the average annual mileage of their primary vehicle.

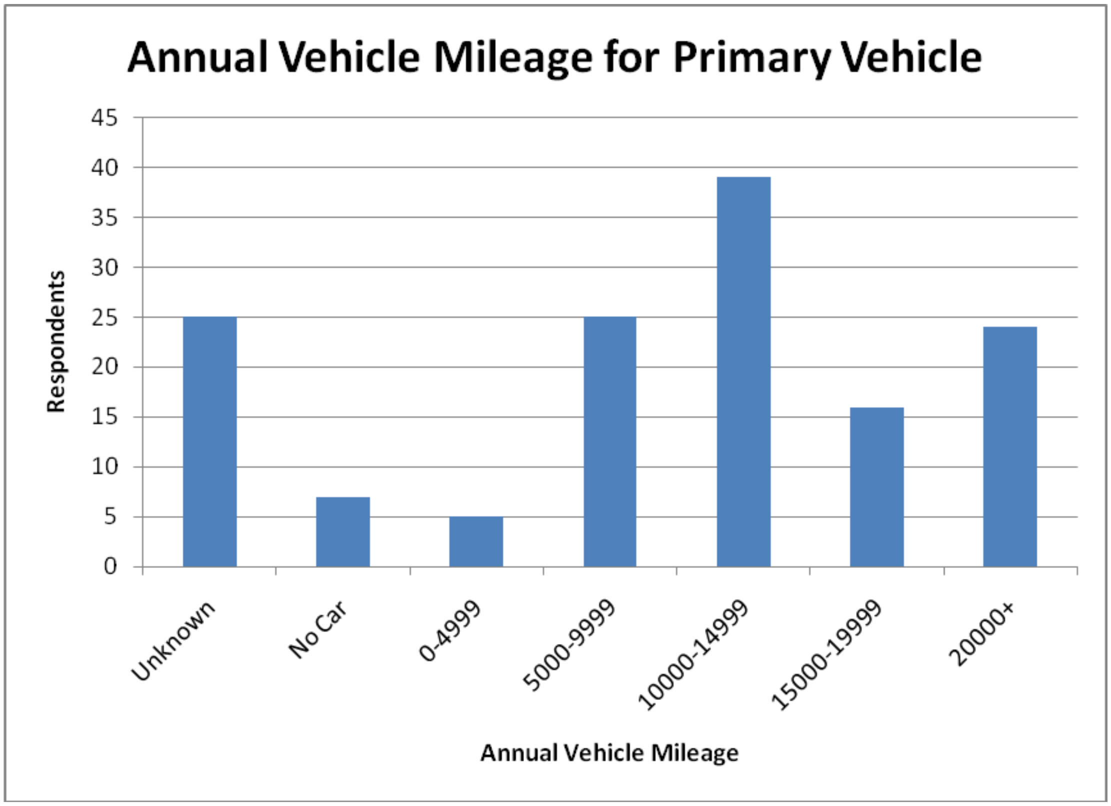


Figure 18 Annual Vehicle Mileage

Primary Vehicle Hybrid. 7% of household used a hybrid electric vehicle as their primary vehicle.

Primary Vehicle Purchase Condition. The purchase condition of 63% of the primary vehicles was new, with the remaining 37% of vehicles purchased used or pre-owned.

Primary Vehicle Purchase Price. The average vehicle purchase price was $19,245 with a median price of $18,000. The minimum purchase price was $1,500 and the maximum purchase price was $46,000. The average purchase price of new vehicles was $23,763. The average purchase price of used vehicles was $11,367. This question had a 4% nonresponse rate.

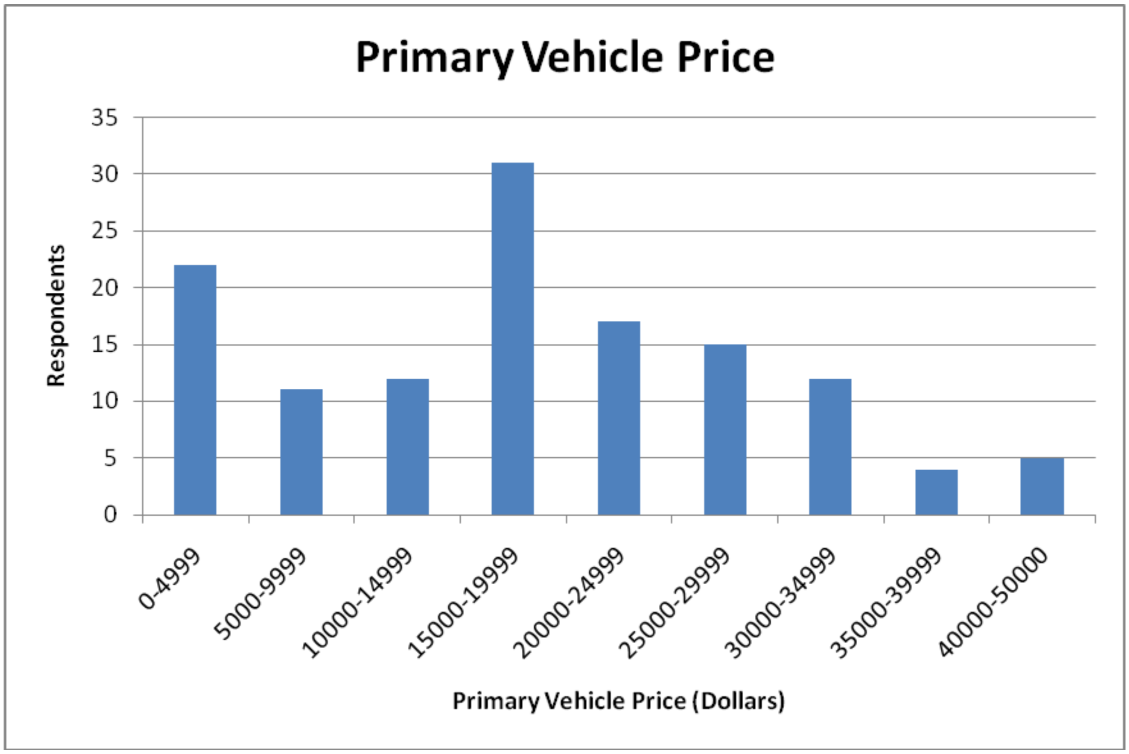


Figure 19 Primary Vehicle Purchase Price

Primary Vehicle Fuel Economy. The average fuel economy was about 27 miles per gallon. The median fuel economy was 25 mpg. 24% of respondents did not know their vehicle's fuel economy.

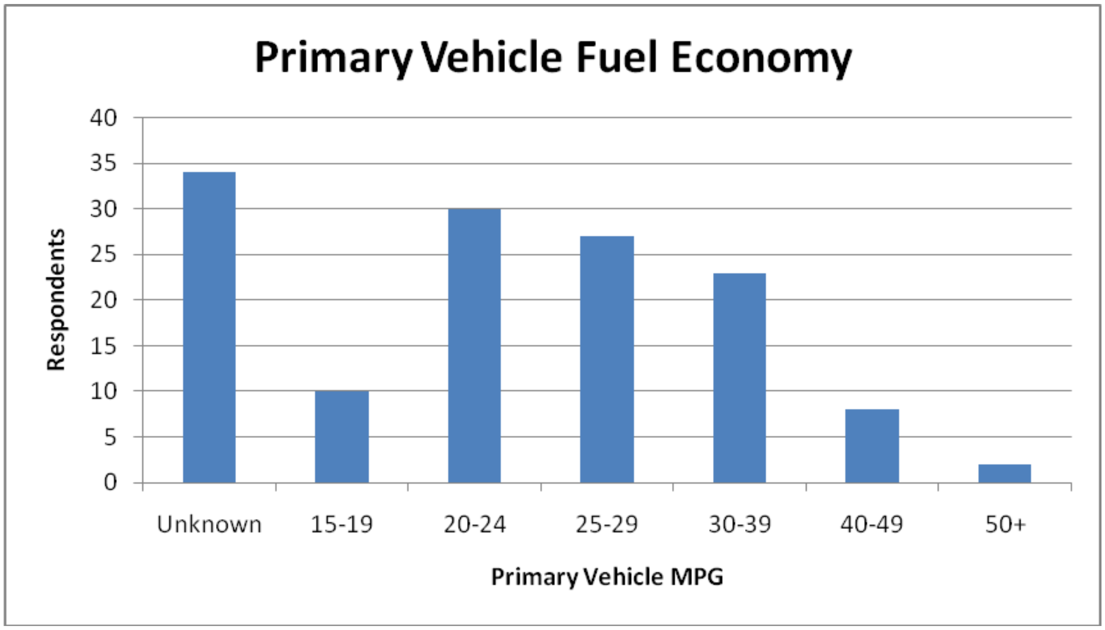


Figure 20 Primary Vehicle Fuel Economy

Primary Vehicle Fuel Capacity. The average fuel economy of vehicles was 14.59 gallons with a median of 12 gallons. 22% of respondents did not know their vehicle's fuel capacity.

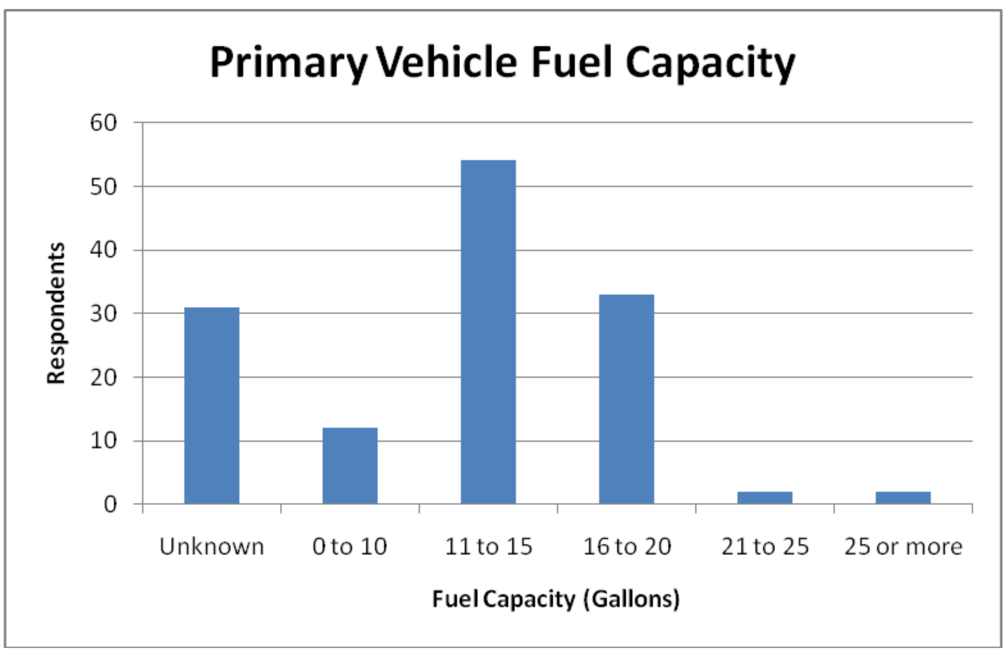


Figure 21 Primary Vehicle Fuel Capacity

Purchase Plans. 62% of respondents planned to buy a vehicle within five years. Of those respondents, 36 respondents plan to buy a new vehicle, 40 respondents plan to buy a used vehicle, and 10 respondents had no preference.

Table 22 Five Year Purchase Plans

Plan to Buy a New Vehicle within 5 Years	Households	Percentage
Yes	87	62%
No	54	38%
No Response	1	0%

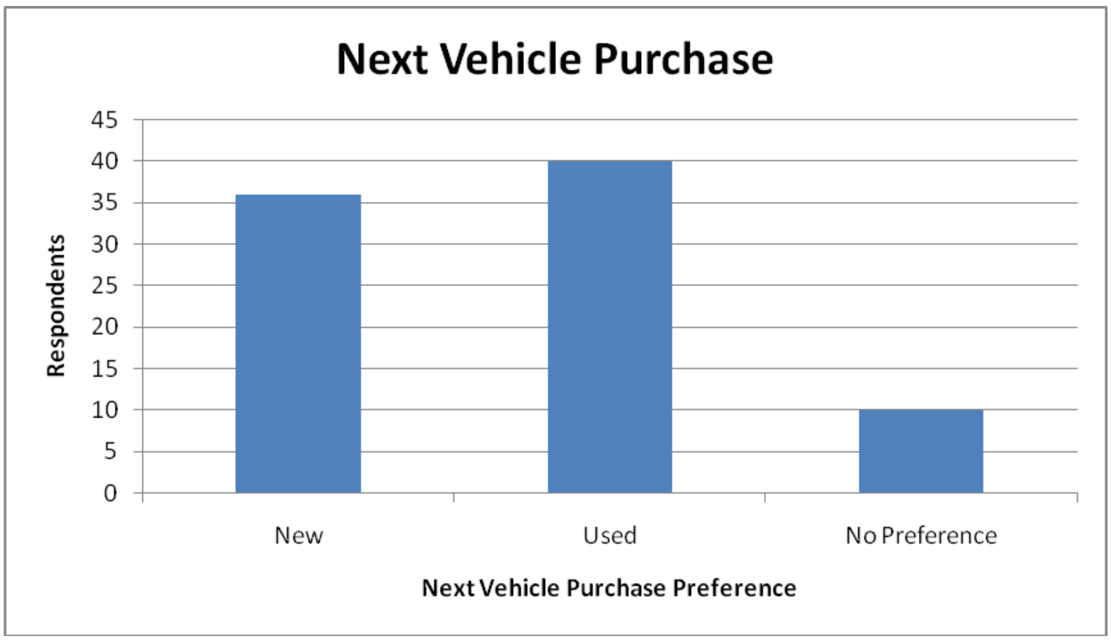


Figure 22 Next Vehicle Purchase Preference

6.3 Stated Preference Games Results

This section describes which choices respondents made during the SP portion of the survey. First, the general pattern of vehicle purchases will be analyzed. Then, each choice game will be analyzed.

Table 23 summarizes how often respondents bought new vehicles in the scenarios. Data in the second and third columns describe the choice frequency of respondents who intended to purchase a vehicle over the next five years. The fifth and sixth columns describe choice frequencies for respondents who did not intend to purchase a vehicle over the next five year.

Table 23 Scenarios In Which Respondents Bought a Vehicle

SP Game	Intend to Buy	Bought a New Vehicle	Rate	Not Intend to Buy	Bought a New Vehicle	Rate
Vehicle Tech	696	312	44.8%	372	108	29.0%
Fuel Tech	312	172	55.1%	216	69	31.9%
Taxation	288	158	54.9%	192	72	37.5%

As expected, those who intend to buy a vehicle had a higher choice frequency than other households. Also notice that even though household may not intend to purchase a vehicle, they still significantly chose to buy new vehicles in the scenarios.

Table 24 summarizes how often respondents bought new cleaner fuel vehicles in the scenarios. Data in the second and third columns describe the choice frequency of respondents who intended to purchase a vehicle over the next five years. The fifth and sixth columns describe choice frequencies for respondents who did not intend to purchase a vehicle over the next five year.

Table 24 Scenarios in Which Respondents Bought a New Non-Conventional Gasoline Vehicle

SP Game	Intend to Buy	Bought a New Vehicle	Rate	Not Intend to Buy	Bought a New Vehicle	Rate
Vehicle Tech	696	189	27.2%	372	70	18.8%
Fuel Tech	312	121	38.8%	216	67	31.0%
Taxation	288	108	37.5%	192	68	35.4%

By comparing results between Table 23 and Table 24, we see that respondents who did not intend to purchase a vehicle tended to buy non-conventional vehicles over gasoline vehicles. This may imply that those who did not intend to buy a new vehicle do so because they see their current vehicle as their most preferable gasoline vehicle. It may also imply that as gasoline prices increase or a VMT tax is implemented, all households may explore new options.

6.3.1 Vehicle Technology Game Results

Eighty-nine respondents were given the vehicle technology game. With each answering 12 scenarios, there were 1068 responses in this game. Section 4.3.1 describes the design of the vehicle technology game.

Table 25 summarizes the choices made from all responses. Keeping one's *current vehicle* was the most popular choice. The other options, which are combinations of buying a new vehicle and keeping or selling one's current vehicle, were chosen in significant numbers. The choice of selling one's vehicle seems unlikely, which follows patterns from the literature.

Table 25 SP Game 1 Choice Results

Choice	Index	2010	2011	2012	2013	2014	2015	Total
Keep Current Vehicle	0	131	118	113	113	84	89	648
Buy New Gasoline, Sell Current Vehicle	1	16	18	19	13	21	20	107
Buy New Hybrid, Sell Current Vehicle	2	9	13	9	15	20	12	78
Buy New Electric, Sell Current Vehicle	3	4	8	8	7	18	17	62
Buy New Gasoline, Keep Current Vehicle	4	2	6	6	5	3	3	25
Buy New Hybrid, Keep Current Vehicle	5	6	4	11	12	11	16	60
Buy New Electric, Keep Current Vehicle	6	10	11	12	11	19	18	81
Sell Current Vehicle	7	0	0	0	2	2	3	7

Table 26 tallies the choices by vehicle technology chosen. *New gasoline, hybrid,* and *electric vehicles* have similar choice totals. Also of note are the decreases in keeping one's current vehicle from 2010 to 2011 and from 2013 to 2014. The first drop may be because less than half of the year remained to purchase a new vehicle. The second drop may indicate that the three year time window introduces enough uncertainty to influence decisions or that the designs for 2014 and 2015 include vehicle technology that closely match what respondents are looking for to change vehicles.

Table 26 SP Game 1 Vehicle Type Choice

Vehicle Type Choice	Index	2010	2011	2012	2013	2014	2015	Total
Current vehicle	0	131	118	113	113	84	89	648
New Gasoline Vehicle	1	18	24	25	18	24	23	132
New Hybrid Vehicle	2	15	17	20	27	31	28	138
New Electric Vehicle	3	14	19	20	18	37	35	143
Sell Current Vehicle	4	0	0	0	2	2	3	7

Table 27 replicates Table 26 but shows the vehicle type choice as a percentage of all choices for that year. The *current vehicle* option has a decreasing choice share.

Choice (1), a *new gasoline vehicle*, has a consistent share while choices (2) and (3), a *new hybrid* and *electric vehicle* respectively, increase in share. This shows that maturing vehicle technology may have an impact on adoption rates; this result follows expectations.

Table 27 SP Game 1 Vehicle Type Choice as Percentage

Vehicle Type Choice	Index	2010	2011	2012	2013	2014	2015
Current vehicle	0	74%	66%	63%	63%	47%	50%
New Gasoline Vehicle	1	10%	13%	14%	10%	13%	13%
New Hybrid Vehicle	2	8%	10%	11%	15%	17%	16%
New Electric Vehicle	3	8%	11%	11%	10%	21%	20%
Sell Current Vehicle	4	0%	0%	0%	1%	1%	2%

Figure 23 shows that the increase in electric vehicle usage may coincide with a decrease in the average vehicle price for electric vehicles shown to respondents in the scenarios from 2010 to 2014.

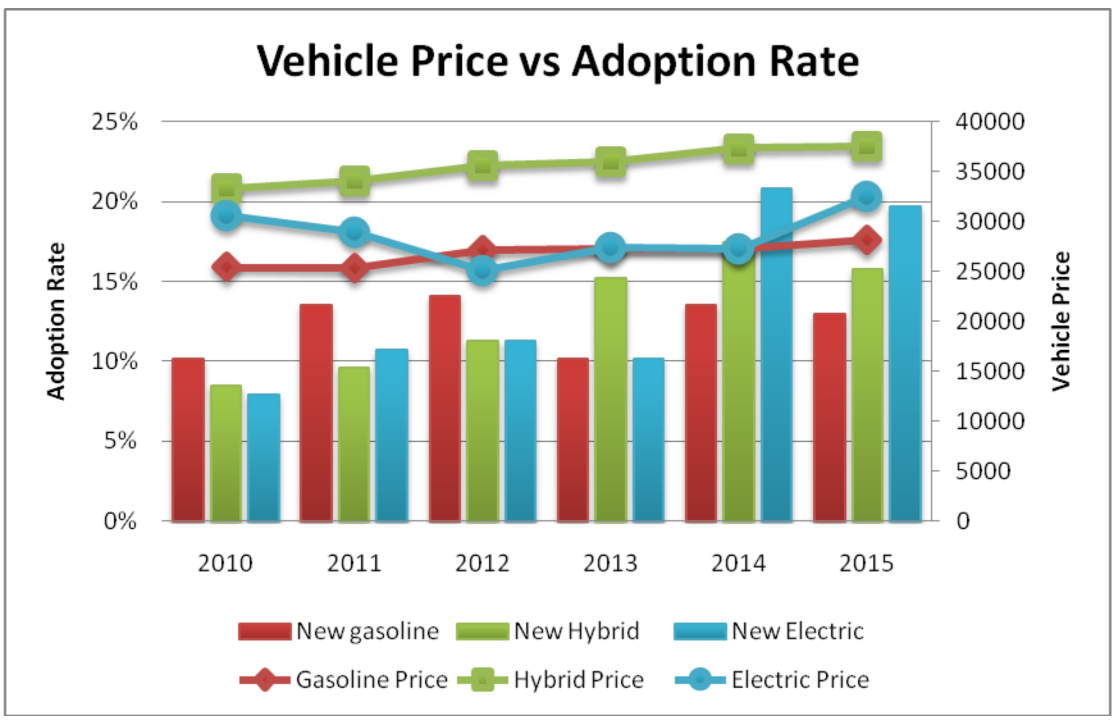


Figure 23 Vehicle Prive versus Adoption Rate

Figure 24 shows that EV adoption increases as electric vehicle range increases.

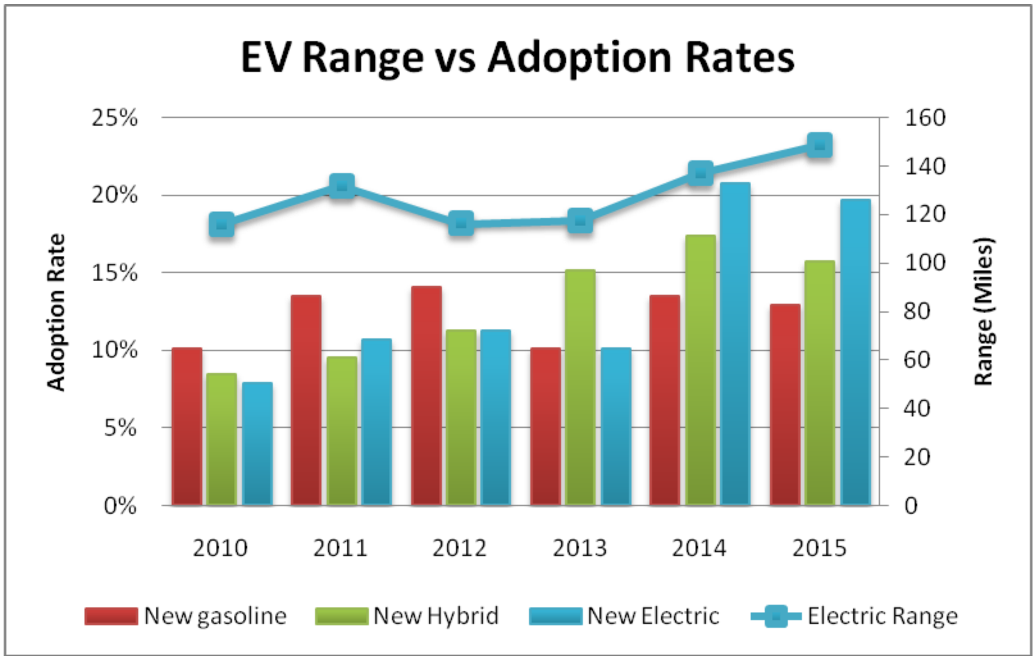


Figure 24 Electric Vehicle Range versus Adoption Rate

Figure 25 shows that although there is a steady increase in gasoline vehicle fuel economy, gasoline vehicle adoption remains steady. In contrast, hybrid electric vehicle purchases increase as the average mpg of hybrids increases with time.

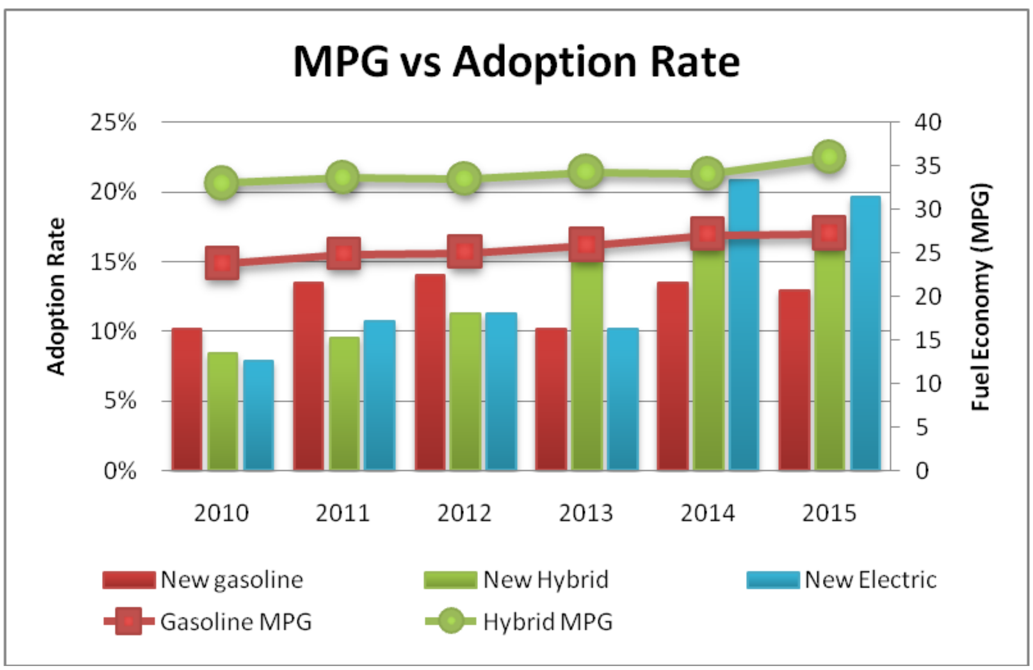


Figure 25 MPG versus Adoption Rate

6.3.2 Fuel Technology Game Results

Forty-four respondents were given the fuel technology game. With each answering 12 scenarios, there were 528 responses in this game. Section 4.3.2 describes the design of the vehicle technology game.

Table 28 summarizes the choices made from all responses. Keeping one's *current vehicle* was the most popular choice as in the first game. All new vehicles options were chosen in significant numbers.

There is a drop in current vehicle retention between 2012 and 2015. These drops are likely attributed to increases in the price of gasoline. In the 2012 period, this decrease in retention is supplemented by an increase in *alternative fuel vehicles* and *plug-in hybrids*. This is likely attributed to the similarity of gasoline vehicles to *alternative fuel vehicles* and the versatility to change between electric and gasoline modes for the *plug-in electric vehicle*. During the 2015 period, the decrease in retention is supplemented by purchases of *plug-in hybrid vehicles* and *electric vehicles.*

New gasoline vehicle purchases are consistent annually. As noted above, *electric vehicles* and *plug-in hybrid vehicle* purchases increase. *Alternative fuel vehicle* purchases increase between 2011 and 2012 then remain constant. *Diesel vehicles* were unpopular with respondents. The choice of selling one's vehicle seems unlikely, which follows patterns from the literature.

Table 28 SP Game 2 Vehicle Choice

Vehicle Choice	Index	2010	2011	2012	2013	2014	2015	Total
Current Vehicle	0	65	62	47	43	43	27	287
New Gasoline Vehicle	1	9	10	10	8	8	8	53
New Alternative Fuel Vehicle	2	5	3	11	8	9	11	47
New Diesel Vehicle	3	0	4	3	7	2	2	18
New Electric Vehicle	4	3	3	5	6	11	16	44
New Plug-In Hybrid Vehicle	5	6	6	12	16	15	23	78
Sell Current Vehicle	6	0	0	0	0	0	1	1

Table 29 replicates Table 28 but shows the vehicle type choice as a percentage of all choices for that year. The *current vehicle* option has a decreasing choice share. Choice (1), a *new gasoline vehicle*, has a consistent share while choices (4) and (5), a *new electric* and *plug-in hybrid vehicle* respectively, increase in share. This shows that increasing fuel prices and new technology may have an impact on adoption rates; this result follows expectations.

Table 29 SP Game 2 Vehicle Choice as Percentage

Vehicle Choice	Index	2010	2011	2012	2013	2014	2015
Current Vehicle	0	74%	70%	53%	49%	49%	31%
New Gasoline Vehicle	1	10%	11%	11%	9%	9%	9%
New Alternative Fuel Vehicle	2	6%	3%	13%	9%	10%	13%
New Diesel Vehicle	3	0%	5%	3%	8%	2%	2%
New Electric Vehicle	4	3%	3%	6%	7%	13%	18%
New Plug-In Hybrid Vehicle	5	7%	7%	14%	18%	17%	26%
Sell Current Vehicle	6	0%	0%	0%	0%	0%	1%

As gasoline prices increase, Figure 26 shows that households began to purchase more BEVs and PHEVs. Although alternative fuel prices are lower than gasoline prices, AFV adoption was relatively flat.

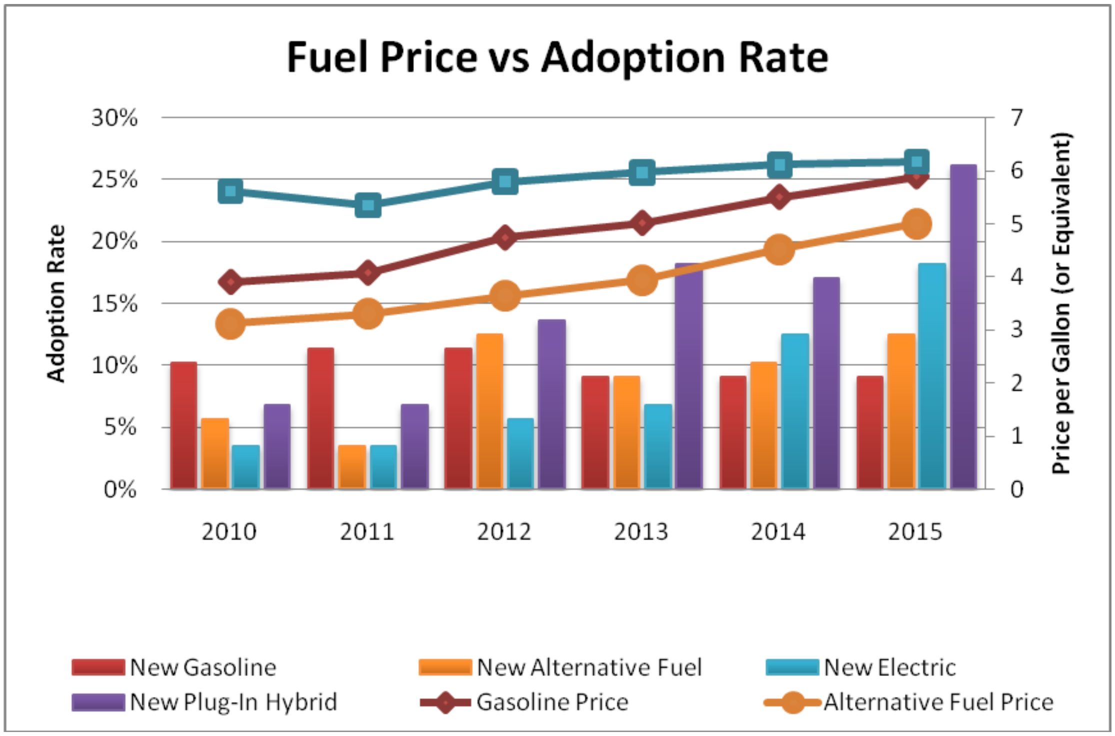


Figure 26 Fuel Price versus Adoption Rate

Figure 27 and Figure 28 show the average fuel economy to expect from vehicles for each fuel type. Although gasoline fuel economy is steadily improving, adoption of gasoline vehicles remains consistent. Electric vehicle adoption (BEVs and PHEVs) increases coincide with electric MPGe increases.

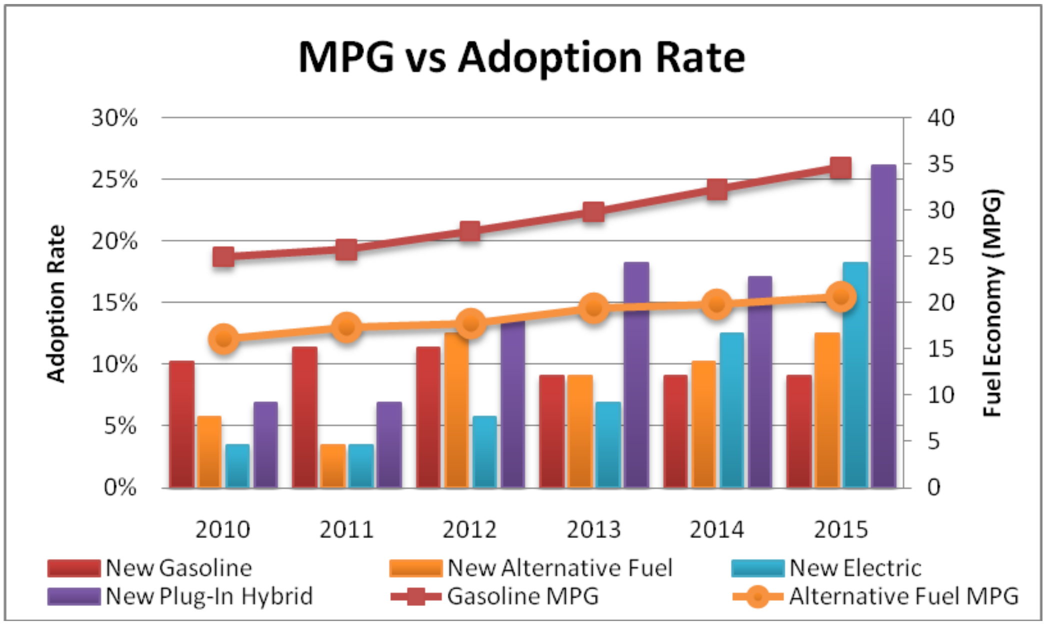


Figure 27 Gasoline and Alterative Fuel MPG versus Adoption Rate

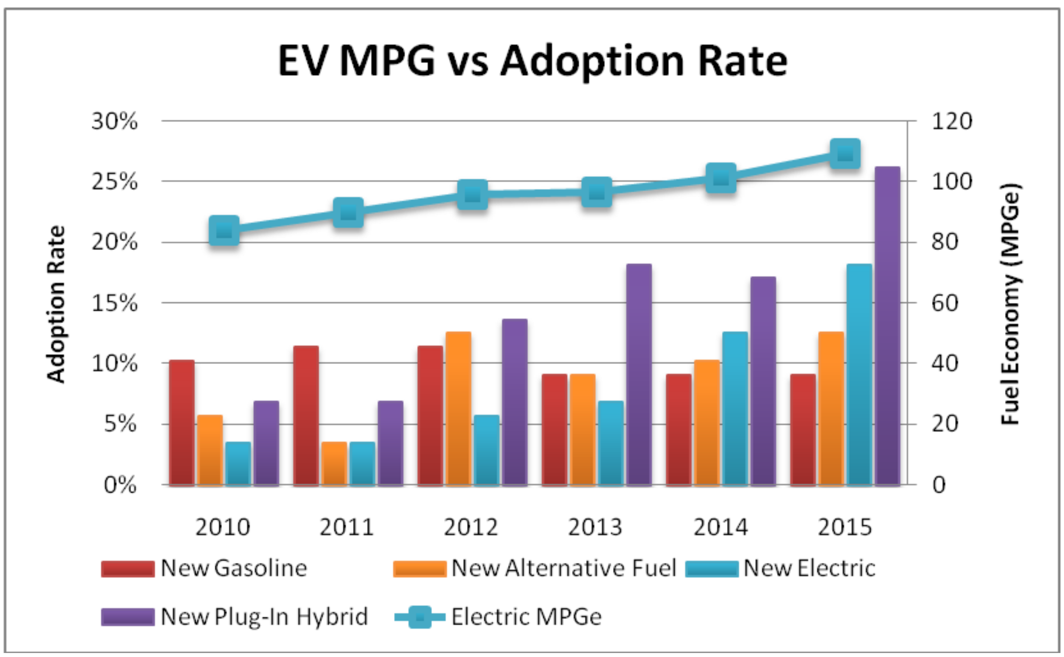


Figure 28 Electric Vehicle MPGe versus Adoption Rate

6.3.3 Toll and Taxation Game Results

Forty respondents were given the toll and taxation game. With each answering 12 scenarios, there were 480 responses in this game. Section 4.3.3 describes the design of the toll and taxation game.

Table 30 summarizes the choices made from all responses. Keeping one's *current vehicle* was the most popular choice. The options which are combinations of buying a new vehicle and keeping or selling one's current vehicle were chosen in significant numbers. Driving one's current vehicle less also appears in significant quantities. The choice of selling one's vehicle seems unlikely, which follows patterns from the literature.

Table 30 SP Game 3 Choice Results

Choice	Index	2010	2011	2012	2013	2014	2015	Total
Keep Current Vehicle	0	48	50	35	24	23	22	202
Keep Current Vehicle, Drive Less	1	0	0	14	11	12	11	48
Buy New Gasoline, Sell Current Vehicle	2	4	4	4	6	7	8	33
Buy New Hybrid, Sell Current Vehicle	3	4	1	3	4	3	5	20
Buy New Electric, Sell Current Vehicle	4	1	2	2	11	9	5	30
Buy New Gasoline, Keep Current Vehicle	5	3	3	3	3	5	4	21
Buy New Hybrid, Keep Current Vehicle	6	12	11	4	3	2	6	38
Buy New Electric, Keep Current Vehicle	7	4	5	11	14	15	15	64
Sell Current Vehicle	8	4	4	4	4	4	4	24

Table 31 tallies the choices by vehicle type chosen. *New gasoline* and *hybrid vehicles* have similar choice totals which may be because of the similarity in policies between the two options.

There is a decrease in keeping one's *current vehicle* in 2013, which is the second year a vehicle-miles-traveled (VMT) tax is adopted. This drop corresponds to an increase in the adoption rate of *electric vehicles*. *New hybrid vehicle* purchases decrease annually with a spike in 2015. The decrease may be attributed to the phasing out of policies encouraging hybrid vehicle adoption.

Table 31 SP Game 3 Vehicle Type Choice

Vehicle Type Choice	Index	2010	2011	2012	2013	2014	2015	Total
Current vehicle	0	48	50	49	35	35	33	250
New Gasoline Vehicle	1	7	7	7	9	12	12	54
New Hybrid Vehicle	2	16	12	7	7	5	11	58
New Electric Vehicle	3	5	7	13	25	24	20	94
Sell Current Vehicle	4	4	4	4	4	4	4	24

Table 32 replicates Table 31 but shows the vehicle type choice as a percentage of all choices for that year. The *current vehicle* option has a decreasing choice share. Choice (1) and (3), a *new gasoline* and *electric vehicle* respectively, have increasing shares while choice (2), a *new hybrid* v*ehicle*, decreases in share. This shows that taxation policy, especially VMT taxes, may have an impact on adoption rates; this result follows expectations.

Table 32 SP Game 3 Vehicle Type Choice as Percentage

Vehicle Type Choice	Index	2010	2011	2012	2013	2014	2015
Current vehicle	0	60%	63%	61%	44%	44%	41%
New Gasoline Vehicle	1	9%	9%	9%	11%	15%	15%
New Hybrid Vehicle	2	20%	15%	9%	9%	6%	14%
New Electric Vehicle	3	6%	9%	16%	31%	30%	25%
Sell Current Vehicle	4	5%	5%	5%	5%	5%	5%

Figure 29 shows how BEV adoption coincides with the introduction of VMT fees for all vehicles. BEV VMT fees are consistently lower than the other vehicles, which may explain why BEV adoption was high after 2012.

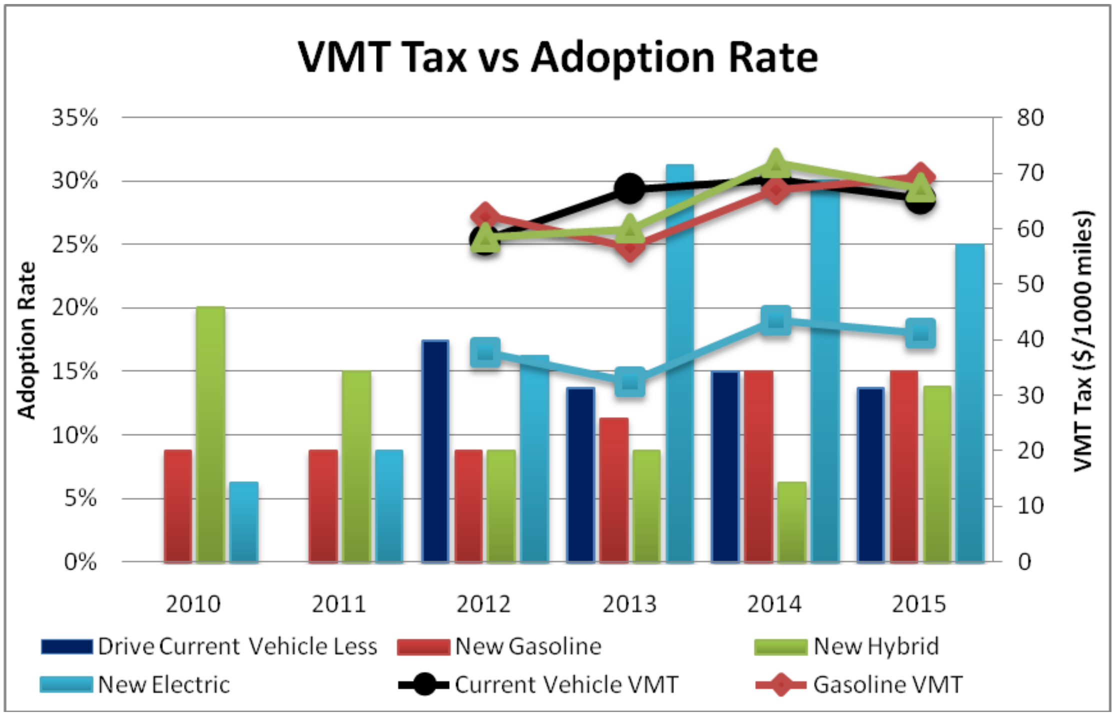


Figure 29 VMT Tax versus Adoption Rate

Chapter 7: Results – Modeling

In this chapter, we will predict the tradeoff that households place on vehicle technology, fuel technology, and taxation policy in vehicle type choice. Because this is a preliminary survey with a small sample size, three independent models will be used. Only model estimation will be conducted since SP-only models are not effective at predicting market share and since no policy or sensitivity analysis is intended for this project.

The decision makers in each model are individual households. We assume that each respondent makes decisions for the entire household. This assumption is common in survey and discrete choice literature.

The general utility function structure used in estimating the model is as follows:

$$U_{ni} = \alpha S_n + \beta V_n + \gamma X_i + \varepsilon_{ni}$$

where:
U_{ni} = the utility for individual *n* and alternative *i*
S_n = a vector of socioeconomic characteristics for individual *n* and his household
α = a vector of coefficients corresponding to S_n
V_n = a vector of current vehicle characteristics for individual *n*'s household
β = a vector of coefficients corresponding to V_n
X_i = a vector of characteristics for alternative *i*
γ = a vector of coefficients corresponding to X_i
ε_{ni} = error term

The socioeconomic portion of the utility was not included in any of the models because of the small sample size. Since the sample is relatively small, adding more variables to the utility functions would likely make the estimated coefficients less significant. With a larger sample, socioeconomic results would likely increase the accuracy of the model and make forecasts more realistic.

A multinomial logit model was chosen for the three SP models because of its simple structure and extensive use in the literature. A MNL model has the following choice probabilities:

$$P_{in} = \frac{e^{U_{in}}}{\sum_{j \in C} e^{U_{jn}}}$$

where:
P_{in}= the probability of choosing alternative *i* for decision maker *n*
U_{in} = the utility of alternative *i* for decision maker *n*
C = the choice set for the model

The limitations of MNL models are that they: (1) cannot handle random taste variation (heterogeneity), (2) does not allow for flexible substitution patterns (limited to independence of irrelevant alternatives, IIA), (3) cannot handle correlation of error terms between observations from the same respondent.

7.1 Vehicle Technology Model

Table 33 Model Estimation for Vehicle Technology Game

Coefficient	Included in Utility: Current	Gasoline	Hybrid	Electric	Value	T-stat
Vehicle Price ($10,000)		✓	✓	✓	-0.476	-4.9
Fuel Economy (MPG)	✓	✓	✓		0.023	1.6
Electric Vehicle Range (100 mi)				✓	0.314	2.0
Emissions Level (% difference)	✓	✓	✓		-0.535	-1.4
Dummy (Large Car Gasoline)		✓			-0.443	-0.9
Dummy (Minivan Gasoline)		✓			0.995	3.4
Dummy (SUV Gasoline)		✓			0.961	3.7
Dummy (Mid-size Car Hybrid)			✓		0.445	2.0
Dummy (Mid-size Car Electric)				✓	0.406	1.9
Number of Cars in Household				✓	-0.234	-2.3
Not Intend to Buy Vehicle in Next Five Years	✓				0.673	4.3
ASC - New Gasoline Vehicle		✓			-0.593	-1.9
ASC - Hybrid Vehicle			✓		-0.388	-0.9
ASC - Electric Vehicle				✓	-0.082	-0.1
Likelihood with Zero Coefficients					-1279.55	
Final Value of Likelihood					-956.09	
"Rho-Squared" with respect to Zero					0.2528	
"Rho-Squared" with respect to Constants					0.0709	
Number of Observations					923	

Table 33 shows the model estimation for the vehicle technology game. For the vehicle technology model, the choice set was limited to: (1) keeping the current vehicle, (2) buying a new gasoline vehicle, (3) buying a new hybrid vehicle, and (4) buying a new battery electric vehicle. The estimated coefficients have the following properties:

Vehicle Price. The vehicle price coefficient was negative and significant. As the cost of a new vehicle increases, households are less likely to buy the vehicle.

Fuel Economy. The fuel economy coefficient was positive as expected and may be significant to a 10% significance level. Fuel efficient vehicles are more attractive to consumers.

Electric Vehicle Range. As the range of electric vehicles increase, consumers were more likely to choose a new BEV. This result was positive and significant.

Emissions Level. As the emissions levels of vehicles increased, there was a decrease in vehicle utility. This result was not significant.

Vehicle Size Dummy Variables. Vehicle size dummy variables were used to show that some vehicle types had a varying preference among consumers. Gasoline minivans were preferred over other vehicle sizes; this is likely due to a lack of hybrid and electric minivans in the marketplace. Gasoline SUVs were also preferred over other vehicle sizes and types. Mid-size hybrid and electric cars were preferred over other vehicle types and sizes as well.

Large gasoline cars were less preferred; this could be due to the similar characteristics between large cars and Minivans/SUVs. Large cars may be perceived as giving consumers very little return (in price, cargo space, and seating comfort) over mid-size cars.

Vehicles per Household. As the number of vehicles in a household increases, battery electric vehicles become less attractive. This runs counter to the "hybrid household hypothesis" and may need further study.

Intent to Purchase Vehicle. Households who did not intend to buy a vehicle over the next five years were more likely to keep their current vehicle. This implies that respondents could be consistent with their intentions.

Alternative Specific Constants. Only the new gasoline vehicle ASC was significant. All ASCs had their expected sign, but the gasoline vehicle ASC was closer to zero than expected but was very insignificant.

7.2 Fuel Technology Model

Table 34 shows the model estimation for the fuel technology game. For the fuel technology model, the choice set was limited to:

(1) keeping the current vehicle
(2) buying a new gasoline vehicle
(3) buying a new alternative fuel vehicle
(4) buying a new diesel vehicle
(5) buying a new battery electric vehicle
(6) buying a new plug-in electric vehicle.

The estimated coefficients have the following properties:

Fuel Price. Since gasoline and alternative fuels have similar characteristics, they shared a price coefficient in this model. This coefficient was significant and negative which is expected. Diesel fuel and electricity prices also were negative and significant. The price of electricity appears to have a less negative impact, which may be attributed to higher fuel efficiency for electric vehicles which would correspond to a lower cost per mile.

Table 34 Model Estimation for Fuel Technology Game

Coefficient	Included in Utility: Current	Gasoline	AFV	Diesel	BEV	PHEV	Value	T-stat
Gasoline & Alternative Fuel Price	✓	✓	✓				-0.716	-6.2
Diesel Fuel Price				✓			-0.678	-2.0
Electricity Price					✓	✓	-0.404	-2.8
Gasoline & Alternative Fuel Tax	✓	✓	✓				-0.226	-0.5
Diesel Fuel Tax				✓			-3.289	-2.1
Electricity Tax					✓	✓	-1.752	-0.8
Gasoline Vehicle & AFV MPG	✓	✓	✓				0.018	1.6
Diesel Vehicle MPG	✓			✓			0.071	2.6
Electric Vehicle MPGe					✓	✓	0.018	2.3
Refueling Station Distance (mi)	✓	✓	✓	✓			-0.019	-1.6
EV Charging Time (hr)					✓	✓	-0.018	-1.8
Number of Cars in Household					✓		0.130	0.6
Not Intend to Buy Vehicle in Next Five Years	✓						0.453	1.9
ASC - New Gasoline Vehicle		✓					-1.637	-8.0
ASC - Alternative Fuel Vehicle			✓				-2.503	-5.3
ASC - Diesel Vehicle				✓			-6.921	-2.8
ASC - Electric Vehicle					✓		-3.318	-2.3
ASC - Plug-in Electric Vehicle						✓	-1.805	-1.3
Likelihood with Zero Coefficients								-709.53
Final Value of Likelihood								-542.46
"Rho-Squared" with respect to Zero								0.3145
"Rho-Squared" with respect to Constants								0.1034
Number of Observations								396

Fuel Tax. The fuel tax coefficients were typically insignificant and negative. This may be attributed to a lack of variation in some tax levels (e.g. electricity tax) or from an overshadowing of fuel price over tax price. Only the diesel tax coefficient was significant.

Fuel Efficiency. All fuel efficiency coefficients were positive as expected. The gasoline vehicle and AFV MPG coefficients may be significant to a 10% significance level. This lack of significance may indicate that when there are alternatives to gasoline, fuel price is more important to consumers than fuel efficiency. Coincidentally, the coefficient for electric vehicle MPGe was the same as the gasoline vehicle / AFV MPG coefficient.

Refueling Station Distance. As it becomes more difficult to reach a fueling station, vehicles that run on that fuel are less attractive.

Charging Time. Electric vehicle charging time was significant to a 10% significance level. This means that as charging time increases, BEVs and PHEVs become less attractive.

Vehicles per Household. In this model, the number of vehicles in a household has a positive but insignificant effect on BEV purchases. The “hybrid household hypothesis” may hold in this case if more observations could be found.

Intent to Purchase Vehicle. Households who did not intend to buy a vehicle over the next five years were more likely to keep their current vehicle. This implies that respondents could be consistent with their intentions.

Alternative Specific Constants. All the ASCs, except for PHEVs, were consistent and negative. This implies that the current vehicle is by default most preferable. The results show a strong dislike for diesel vehicles and possible preference towards PHEVs.

7.3 Taxation Policy Model

Table 35 shows the model estimation for the vehicle technology game. For the vehicle technology model, the choice set was limited to: (1) keeping the current vehicle, (2) buying a new gasoline vehicle, (3) buying a new hybrid vehicle, and (4) buying a new battery electric vehicle.

The estimated coefficients have the following properties:

VMT Tax. A new vehicle-miles-traveled fee has a significant influence on new vehicle purchases. Hybrid and gasoline vehicles had similar negative effects from the new VMT fee. The electric vehicle VMT effect was less negative which may be attributed to a lower VMT fee in general or a more negative ASC for electric vehicles.

Table 35 Model Estimation for Taxation Policy Game

Coefficient	Included in Utility: Current	Gasoline	Hybrid	Electric	Value	T-stat
Gasoline Vehicle VMT Tax ($/1000 mi)	✓	✓			-0.019	-5.4
Hybrid Vehicle VMT Tax			✓		-0.020	-3.7
Electric Vehicle VMT Tax				✓	-0.013	-2.1
Hybrid Vehicle Deduction ($1000)			✓		0.219	1.4
Electric Vehicle Deduction				✓	-0.121	-1.7
Gasoline and Hybrid Vehicle Toll (%)	✓	✓	✓		0.072	0.1
Electric Vehicle Toll				✓	-0.604	-1.0
Number of Cars in Household				✓	-0.944	-6.0
Not Intend to Buy Vehicle in Next Five Yrs	✓				1.319	-6.0
ASC – New Gasoline Vehicle		✓			-1.146	-6.8
ASC – New Hybrid Vehicle			✓		-1.164	-3.4
ASC – New Electric Vehicle				✓	1.416	0.9
Likelihood with Zero Coefficients						-632.15
Final Value of Likelihood						-472.76
"Rho-Squared" with respect to Zero						0.2521
"Rho-Squared" with respect to Constants						0.1139
Number of Observations						456

Vehicle Deductions. Hybrid vehicle deductions were positive and not significant. The electric vehicle deductions were negative and significant to a 10% significance level. This is counterintuitive as a deduction is essentially a refund. More variation in vehicle deduction levels may be necessary in future surveys. Additionally, it may be appropriate to add a dummy variable to future models for situation in which no deduction occurred (i.e. perhaps there is a “value of no deduction”).

Toll Rates. Tolling policy had an insignificant effect on vehicle purchases. This is likely due to a lack of toll facilities in the Washington metro area.

Vehicles per Household. As the number of vehicles in a household increases, battery electric vehicles become less attractive. This runs counter to the "hybrid household hypothesis" and may need further study.

Intent to Purchase Vehicle. Households who did not intend to buy a vehicle over the next five years were more likely to keep their current vehicle. This implies that respondents could be consistent with their intentions.

Alternative Specific Constants. The ASCs for new gasoline and hybrid vehicles were both negative and significant. The electric vehicle ASC was unexpectedly positive but not significant.

Chapter 8: Future Work and Conclusion

This section describes future work on the survey. Since this was a preliminary survey, a secondary purpose of the study was to determine ways to make improvements.

8.1 Future Work

8.1.1 Survey Design

Some minor changes could be made to the survey to reduce its length or to gain more information. Changes could be made to improve the taxation policy game.

Reducing the current vehicle section to a question about the make and model of the primary vehicle could reduce the length of the survey. This would require an extensive database of vehicle makes and models over the last 15 to 20 years. The option to input vehicle characteristics should still be offered for models not covered or people who don’t know their vehicle’s model name.

The taxation policy game had the least number of attributes and its model created the unexpected result of disutility for deductions. Tolling policy does not seem to factor into vehicle decisions for a significant number of people in the target population. Additionally, the introduction of fees for purchasing gasoline vehicles may be an interesting policy to analyze since it is a relatively simple policy to implement.

8.1.2 Modeling

Because of the independence from irrelevant alternatives (IIA) property of logit, other modeling techniques with flexible substitution patterns could be used. From Section 2, we saw that Brownstone and Train were able to use mixed logit and probit to achieve more realistic substitution patterns. Additionally, since this survey looks at vehicle ownership decisions over time, dynamic discrete choice models may be used.

Further analysis of the effects of vehicles per household may be warranted. Prior research suggested that households with more vehicles are more likely to adopt new vehicle technology. We were not able to replicate that result and a greater modeling emphasis should be placed on that to understand if this assumption is correct.

8.2 Conclusion

This study has presented the life cycle for a preliminary stated preference survey to determine consumer preferences for new vehicle technology. To the author's knowledge, this is the first such public study of consumer preferences for new vehicle technology in the mid-Atlantic region.

A web survey framework, JULIE, was created for making custom web-based stated preference surveys. The object-oriented and MVC nature of JULIE allows it to be highly customizable.

A CASI and web-based survey were conducted during September and October 2010 in suburban and urban Maryland. A sample size of 154 respondents was collected with 141 complete surveys.

Using the measurements from the survey, indicators of consumer vehicle preferences were estimated using a multinomial logit model. Three discrete choice models were estimated for this study, corresponding to the three stated choice games created. These models found significant relationships between new vehicle ownership and vehicle and fuel characteristics as well as new VMT fees.

Appendix A – The Survey (Socioeconomics and RP)

The following appendix provides the questions in the socioeconomic and RP portions of the survey. Each question begins with a question title in capital letters followed by the question text and choice options (if provided).

```
GENDER:
What is your gender?
choice 1, "Male"
choice 2, "Female"

AGE:
What is your age?

EDUCATION:
What is your level of education?
choice 1, Less than high school
choice 2, High school graduate
choice 3, Some college
choice 4, Associate degree
choice 5, Bachelor's degree
choice 6, Graduate or professional degree


HEAD_OF_HOUSEHOLD:
Q Do you consider yourself the head of the household?

INCOME:
What is your household income?
choice 1, Less than $24,999
choice 2, $25,000 to $49,999
choice 3, $50,000 to $74,999
choice 4, $75,000 to $99,999
choice 5, $100,000 to $149,999
choice 6, $150,000 or more

KIDS:
How many children age 12 or under live in your household?
choice 1, 0
choice 2, 1
choice 3, 2
choice 4, 3
choice 5, 4
choice 6, 5
choice 7, More than 5
```

ADOLESCENTS:
How many people age 13 through 17 (13, 14, 15, 16, or 17) live in your household?
choice 1, 0
choice 2, 1
choice 3, 2
choice 4, 3
choice 5, 4
choice 6, 5
choice 7, More than 5

ADULTS:
How many adults (including yourself) age 18 or over live in your household?
choice 1, 1
choice 2, 2
choice 3, 3
choice 4, 4
choice 5, 5
choice 6, More than 5

WORKERS:
How many people in your household work?
choice 1, 0
choice 2, 1
choice 3, 2
choice 4, 3
choice 5, 4
choice 6, More than 4

STATE:
What state do you currently live in?
choice 1, Maryland
choice 2, Virginia
choice 3, District of Columbia
choice 4, Other

ZIPCODE:
What is the zip code of your living place?

HOME_TYPE:
Which of the following best describes your home?
choice 1, College Dorm or similar student-based housing
choice 1, Apartment
choice 2, Condominium
choice 3, Townhouse
choice 4, Rowhouse
choice 5, Single-Family Home, Detached House, or Separated House
choice 6, Other

OCCUPATION:
During most of last week, were you...
choice 1, Working full time (35 hours per week or more)
choice 2, Working part time (less than 35 hours per week)
choice 3, Looking for work
choice 4, Homemaker
choice 5, Going to school
choice 6, Retired
choice 7, Other

COMMUTE:
In miles, how far round-trip is your commute to work or school?
For example, if you drive 10 miles to work and 10 miles back home, then input 20 miles.
If you drive 10 miles to work then 5 miles to pick up your kids and then 10 miles home, then input 25 miles

LICENSE:
Do you have a driver license?

BUY_ANOTHER_VEHICLE:
Does your household plan to buy a vehicle at some point over the next five years?

BUY_NEW_USED:
Do you expect the vehicle you buy to be new or used/pre-owned?
choice 0, New Vehicle
choice 1, Used/Pre-Owned Vehicle
choice 2, No Preference

CARS_PER_HOUSEHOLD:
Q How many car does your household currently have?
choice 0, No Cars in the Household
choice 1, One Car in the Household
choice 2, Two Cars in the Household
choice 3, Three Cars in the Household
choice 4, Four Cars in the Household
choice 5, More than 4 Cars in the Household

MAKE_MODEL_PRIMARY:
What is the make and model of your primary vehicle (the vehicle you drive most often)?
Examples of make and model are: Ford F-150, Toyota Corolla, Ford Fusion, Chevy Malibu, Honda Civic

MAKE_MODEL_SECOND:
What is the make and model of your second vehicle?

MAKE_MODEL_THIRD:
What is the make and model of your third vehicle?

MAKE_MODEL_FOURTH:
What is the make and model of your fourth vehicle?

HOME_PARKING:
Where do you typically park your vehicle(s) when at home?
choice 1, Personal Garage
choice 2, Personal Driveway
choice 3, On-street
choice 4, Outdoor Parking Lot
choice 5, Parking Garage or Covered Parking Lot
choice 6, Other

WORK_PARKING:
Is parking available at your workplace or school?

PARKING_COST:
How much would it cost you to park at work per month?
If free, type in 0.

VEHICLE_TYPE:
Which of the following types best describes your primary vehicle?
choice 1, Compact / Small Car (Examples: Ford Focus, Toyota Yaris, Honda Civic)
choice 2, Mid-size Car (Examples: Chevy Malibu, Ford Fusion, Toyota Camry)
choice 3, Large Car (Examples: Honda Accord, Chevy Impala, Ford Taurus)
choice 4, Minivan / Van
choice 5, Pickup Truck
choice 6, Sports Utility Vehicle (SUV)

VEHICLE_YEAR:
What is the model year of your primary vehicle?

VEHICLE_MILES:
On average, approximately how many miles does this vehicle travel per year?

VEHICLE_FUEL:
What type of fuel does your primary vehicle use?
choice 1, Gasoline (including hybrid vehicles)
choice 2, Diesel
choice 3, Electric (not including hybrid vehicles)
choice 4, Alternative Fuel (examples: ethanol, natural gas, biodiesel, propane, hydrogen)
choice 5, Other

VEHICLE_HYBRID:
Is your primary vehicle a Hybrid?

VEHICLE_NEW:
Did you buy this vehicle new? (The car has not been owned by anyone else)

PURCHASE_YEAR:
In what year did you purchase your primary vehicle?

VEHICLE_PRICE:
Approximately how much did you pay for this vehicle?

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VEHICLE_MPG:
What is your primary vehicle's fuel efficiency (MPG)?

VEHICLE_CAPACITY:
What is the tank capacity (in gallons) of your primary vehicle?
(How many gallons of fuel can you pump into your primary vehicle?)

VEHICLE_SEATING:
How many seats are in your primary vehicle?
choice 1, 2
choice 2, 3
choice 3, 4
choice 4, 5
choice 5, 6
choice 6, 7
choice 7, 8
choice 8, More than 8
```

Appendix B – Experimental Design (Vehicle Technology Game)

GASOLINE VEHICLE

	2010				2011				2012			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car	15500	29	300	0.83	15810	29	300	0.83	16120	29	300	0.83
	16205	31	350	0.77	16529	31	350	0.77	16853	31	350	0.76
	16909	33	400	0.73	17247	33	400	0.72	17585	34	400	0.70
	18318	34	450	0.70	18685	36	450	0.67	19051	38	450	0.64
Midsize	24900	23	300	1.04	25398	23	300	1.04	25896	23	300	1.04
	26032	25	350	0.97	26552	25	350	0.97	27073	25	350	0.96
	27164	26	400	0.92	27707	27	400	0.90	28250	27	400	0.89
	29427	27	450	0.89	30016	28	450	0.85	30604	30	450	0.81
Large	28300	21	300	1.14	28866	21	300	1.14	29432	21	300	1.14
	29586	23	350	1.07	30178	23	350	1.06	30770	23	350	1.05
	30873	24	400	1.01	31490	24	400	0.99	32108	25	400	0.97
	33445	25	450	0.97	34114	26	450	0.93	34783	27	450	0.88
Minivan	24300	20	300	1.20	24786	20	300	1.20	25272	20	300	1.20
	25405	21	350	1.12	25913	22	350	1.11	26421	22	350	1.11
	26509	23	400	1.06	27039	23	400	1.04	27569	24	400	1.02
	28718	24	450	1.02	29293	25	450	0.97	29867	26	450	0.93
SUV	29000	19	300	1.26	29580	19	300	1.26	30160	19	300	1.26
	30318	20	350	1.18	30925	20	350	1.17	31531	21	350	1.17
	31636	22	400	1.12	32269	22	400	1.09	32902	22	400	1.07
	34273	22	450	1.07	34958	23	450	1.02	35644	25	450	0.97
Pickup	22560	17	300	1.41	23011	17	300	1.41	23462	17	300	1.41
	23585	18	350	1.32	24057	18	350	1.31	24529	18	350	1.30
	24611	19	400	1.25	25103	20	400	1.22	25595	20	400	1.20
	26662	20	450	1.20	27195	21	450	1.14	27728	22	450	1.09

	2013				2014				2015			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car	16430	29	300	0.83	16740	29	300	0.83	17050	29	300	0.83
	17177	32	350	0.76	17501	32	350	0.76	17825	32	350	0.75
	17924	35	400	0.69	18262	36	400	0.68	18600	36	400	0.66
	19417	39	450	0.61	19784	41	450	0.58	20150	44	450	0.55
Midsize	26394	23	300	1.04	26892	23	300	1.04	27390	23	300	1.04
	27594	25	350	0.96	28114	25	350	0.95	28635	25	350	0.95
	28793	28	400	0.87	29337	28	400	0.85	29880	29	400	0.83
	31193	31	450	0.77	31781	33	450	0.73	32370	35	450	0.70
Large	29998	21	300	1.14	30564	21	300	1.14	31130	21	300	1.14
	31362	23	350	1.05	31953	23	350	1.04	32545	23	350	1.04
	32725	25	400	0.95	33343	26	400	0.93	33960	26	400	0.91
	35452	29	450	0.84	36121	30	450	0.80	36790	32	450	0.76
Minivan	25758	20	300	1.20	26244	20	300	1.20	26730	20	300	1.20
	26929	22	350	1.10	27437	22	350	1.10	27945	22	350	1.09
	28100	24	400	1.00	28630	25	400	0.98	29160	25	400	0.96
	30441	27	450	0.88	31016	29	450	0.84	31590	30	450	0.80
SUV	30740	19	300	1.26	31320	19	300	1.26	31900	19	300	1.26
	32137	21	350	1.16	32744	21	350	1.15	33350	21	350	1.15
	33535	23	400	1.05	34167	23	400	1.03	34800	24	400	1.01
	36329	26	450	0.93	37015	27	450	0.88	37700	29	450	0.84
Pickup	23914	17	300	1.41	24365	17	300	1.41	24816	17	300	1.41
	25001	19	350	1.30	25472	19	350	1.29	25944	19	350	1.28
	26088	20	400	1.18	26580	21	400	1.15	27072	21	400	1.13
	28262	23	450	1.04	28795	24	450	0.99	29328	26	450	0.94

HYBRID VEHICLE

	2010				2011				2012			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car	21000	42	300	0.57	21420	42	300	0.57	21840	42	300	0.57
	21955	45	350	0.53	22394	45	350	0.53	22833	46	350	0.53
	22909	48	400	0.50	23367	49	400	0.49	23825	49	400	0.49
	24818	49	450	0.49	25315	52	450	0.46	25811	54	450	0.44
Midsize	26000	34	300	0.71	26520	34	300	0.71	27040	34	300	0.71
	27182	36	350	0.66	27725	37	350	0.65	28269	37	350	0.65
	28364	38	400	0.62	28931	39	400	0.61	29498	40	400	0.60
	30727	40	450	0.60	31342	42	450	0.57	31956	44	450	0.54
SUV	40000	21	300	1.14	40800	21	300	1.14	41600	21	300	1.14
	41818	23	350	1.07	42655	23	350	1.06	43491	23	350	1.05
	43636	24	400	1.01	44509	24	400	0.99	45382	25	400	0.97
	47273	25	450	0.97	48218	26	450	0.93	49164	27	450	0.88
Pickup	39000	20	300	1.20	39780	20	300	1.20	40560	20	300	1.20
	40773	21	350	1.12	41588	22	350	1.11	42404	22	350	1.11
	42545	23	400	1.06	43396	23	400	1.04	44247	24	400	1.02
	46091	24	450	1.02	47013	25	450	0.97	47935	26	450	0.93

	2013				2014				2015			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car	22260	42	300	0.57	22680	42	300	0.57	23100	42	300	0.57
	23272	46	350	0.52	23711	46	350	0.52	24150	46	350	0.52
	24284	50	400	0.48	24742	51	400	0.47	25200	53	400	0.46
	26307	57	450	0.42	26804	60	450	0.40	27300	63	450	0.38
Midsize	27560	34	300	0.71	28080	34	300	0.71	28600	34	300	0.71
	28813	37	350	0.65	29356	37	350	0.64	29900	37	350	0.64
	30065	41	400	0.59	30633	42	400	0.58	31200	43	400	0.56
	32571	46	450	0.52	33185	49	450	0.49	33800	51	450	0.47
SUV	42400	21	300	1.14	43200	21	300	1.14	44000	21	300	1.14
	44327	23	350	1.05	45164	23	350	1.04	46000	23	350	1.04
	46255	25	400	0.95	47127	26	400	0.93	48000	26	400	0.91
	50109	29	450	0.84	51055	30	450	0.80	52000	32	450	0.76
Pickup	41340	20	300	1.20	42120	20	300	1.20	42900	20	300	1.20
	43219	22	350	1.10	44035	22	350	1.10	44850	22	350	1.09
	45098	24	400	1.00	45949	25	400	0.98	46800	25	400	0.96
	48856	27	450	0.88	49778	29	450	0.84	50700	30	450	0.80

ELECTRIC VEHICLE

	2010				2011				2012			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car (2-Seat)	18000	0	68	0.00	18360	0	71	0.00	18720	0	75	0.00
	18818	0	69	0.00	19195	0	73	0.00	19571	0	78	0.00
	19636	0	70	0.00	20029	0	75	0.00	20422	0	81	0.00
	21273	0	71	0.00	21698	0	78	0.00	22124	0	86	0.00
Small Car (4-Seat)	20000	0	80	0.00	20400	0	84	0.00	20800	0	88	0.00
	20909	0	90	0.00	21327	0	95	0.00	21745	0	99	0.00
	21818	0	100	0.00	22255	0	105	0.00	22691	0	110	0.00
	23636	0	130	0.00	24109	0	137	0.00	24582	0	143	0.00
Small Car (5-Seat)	20000	0	80	0.00	20400	0	84	0.00	20800	0	88	0.00
	20909	0	90	0.00	21327	0	95	0.00	21745	0	99	0.00
	21818	0	100	0.00	22255	0	105	0.00	22691	0	110	0.00
	23636	0	130	0.00	24109	0	137	0.00	24582	0	143	0.00
Mid-Size (5-Seat)	57400	0	100	0.00	33000	0	100	0.00	25000	0	100	0.00
	60000	0	160	0.00	57600	0	160	0.00	30000	0	160	0.00
	62500	0	240	0.00	60000	0	240	0.00	45000	0	240	0.00
	65000	0	300	0.00	62400	0	300	0.00	60000	0	300	0.00

	2013				2014				2015			
	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.	Price	MPG	Range	Emis.
Small Car (2-Seat)	19080	0	79	0.00	19440	0	83	0.00	19800	0	87	0.00
	19947	0	82	0.00	20324	0	87	0.00	20700	0	92	0.00
	20815	0	87	0.00	21207	0	93	0.00	21600	0	100	0.00
	22549	0	95	0.00	22975	0	104	0.00	23400	0	114	0.00
Small Car (4-Seat)	21200	0	93	0.00	21600	0	97	0.00	22000	0	102	0.00
	22164	0	104	0.00	22582	0	109	0.00	23000	0	115	0.00
	23127	0	116	0.00	23564	0	122	0.00	24000	0	128	0.00
	25055	0	150	0.00	25527	0	158	0.00	26000	0	166	0.00
Small Car (5-Seat)	21200	0	93	0.00	21600	0	97	0.00	22000	0	102	0.00
	22164	0	104	0.00	22582	0	109	0.00	23000	0	115	0.00
	23127	0	116	0.00	23564	0	122	0.00	24000	0	128	0.00
	25055	0	150	0.00	25527	0	158	0.00	26000	0	166	0.00
Mid-Size (5-Seat)	25750	0	100	0.00	26523	0	100	0.00	27318	0	100	0.00
	30900	0	160	0.00	31827	0	160	0.00	32782	0	160	0.00
	46350	0	240	0.00	47741	0	240	0.00	49173	0	240	0.00
	61800	0	300	0.00	63654	0	300	0.00	65564	0	300	0.00

Appendix C – Experimental Design (Fuel Choice Game)

	2010				2011				2012			
	Cost	Tax	MPG	Avail	Cost	Tax	MPG	Avail	Cost	Tax	MPG	Avail
Gasoline Fuel	2.00	0.42	16	5	2.20	0.42	18	5	2.42	0.42	20	5
	2.50	0.65	23	5	2.75	0.65	25	5	3.03	0.65	27	5
	2.75	1.00	30	5	3.03	1.00	32	5	3.33	1.00	34	5
	3.00				3.30				3.63			
	3.50				3.85				4.24			
	4.00				4.40				4.84			
Alternative Fuel (E85)	1.80	0.07	12	50	1.98	0.07	13	50	2.18	0.07	14	50
	2.25	0.15	15	25	2.48	0.15	16	25	2.72	0.15	17	25
	2.48	0.30	19	15	2.72	0.30	20	15	2.99	0.30	21	15
	2.70				2.97				3.27			
	3.15				3.47				3.81			
	3.60				3.96				4.36			
Diesel Fuel	2.00	0.49	22	5	2.20	0.49	24	5	2.42	0.49	26	5
	2.50	0.70	28	5	2.75	0.70	30	5	3.03	0.70	32	5
	2.75	1.05	34	10	3.03	1.05	36	10	3.33	1.05	38	10
	3.00				3.30				3.63			
	3.50				3.85				4.24			
	4.00				4.40				4.84			
Electricity	3.70	0.12	60	4	3.81	0.12	65	4	3.93	0.12	70	3
	4.40	0.20	80	5	4.53	0.20	85	5	4.67	0.20	90	4
	4.90	0.28	100	6	5.05	0.28	105	6	5.20	0.28	110	5
	5.30				5.46				5.62			
	5.70				5.87				6.05			
	6.05				6.23				6.42			

	2013				2014				2015			
	Cost	Tax	MPG	Avail	Cost	Tax	MPG	Avail	Cost	Tax	MPG	Avail
Gasoline Fuel	2.66	0.42	22	5	2.93	0.42	24	5	3.22	0.42	26	5
	3.33	0.65	29	5	3.66	0.65	31	5	4.03	0.65	33	5
	3.66	1.00	36	5	4.03	1.00	38	5	4.43	1.00	40	5
	3.99				4.39				4.83			
	4.66				5.12				5.64			
	5.32				5.86				6.44			
Alternative Fuel (E85)	2.40	0.07	15	25	2.64	0.07	16	25	2.90	0.07	16	25
	2.99	0.15	18	15	3.29	0.15	19	15	3.62	0.15	19	15
	3.29	0.30	22	10	3.62	0.30	23	10	3.99	0.30	24	10
	3.59				3.95				4.35			
	4.19				4.61				5.07			
	4.79				5.27				5.80			
Diesel Fuel	2.66	0.49	28	5	2.93	0.49	30	5	3.22	0.49	32	5
	3.33	0.70	34	5	3.66	0.70	36	5	4.03	0.70	38	5
	3.66	1.05	40	10	4.03	1.05	42	10	4.43	1.05	44	10
	3.99				4.39				4.83			
	4.66				5.12				5.64			
	5.32				5.86				6.44			
Electricity	4.04	0.12	75	3	4.16	0.12	80	2	4.29	0.12	85	2
	4.81	0.20	95	4	4.95	0.20	100	3	5.10	0.20	105	3
	5.35	0.28	115	5	5.51	0.28	120	4	5.68	0.28	125	4
	5.79				5.97				6.14			
	6.23				6.42				6.61			
	6.61				6.81				7.01			

Appendix D – Experimental Design (Taxation Game)

	2010			2011			2012		
	Deduction	Toll	VMT	Deduction	Toll	VMT	Deduction	Toll	VMT
Gasoline Vehicle	0	100%		0	100%		0	100%	30
	0	100%		0	100%		0	100%	60
	0	100%		0	100%		0	100%	90
Electric Vehicle	2500	100%		2500	100%		2500	100%	10
	5000	75%		5000	75%		5000	75%	30
	7500	50%		7500	50%		7500	50%	60
Hybrid Vehicle	0	100%		0	100%		0	100%	30
	1000	90%		1000	90%		0	90%	60
	3000	75%		3000	75%		1000	75%	90
Current Vehicle	0	100%		0	100%		0	100%	30
	0	100%		0	100%		0	100%	60
	0	100%		0	100%		0	100%	90

	2013			2014			2015		
	Deduction	Toll	VMT	Deduction	Toll	VMT	Deduction	Toll	VMT
Gasoline Vehicle	0	100%	30	0	100%	4	0	100%	40
	0	100%	60	0	100%	7	0	100%	70
	0	100%	90	0	100%	10	0	100%	100
Electric Vehicle	2500	100%	10	100	100%	2	2500	100%	20
	5000	75%	30	75	75%	4	3750	75%	40
	7500	50%	60	50	50%	7	5000	50%	70
Hybrid Vehicle	0	100%	30	100	100%	4	0	100%	40
	0	90%	60	100	90%	7	0	90%	70
	1000	75%	90	75	75%	10	0	75%	100
Current Vehicle	0	100%	30	100	100%	4	0	100%	40
	0	100%	60	100	100%	7	0	100%	70
	0	100%	90	100	100%	10	0	100%	100

Appendix E – Orthogonal Arrays

Orthogonal Array for Vehicle Technology Game:

Scenario Num	Price	MPG	Range	Emissions	Size
0	0	0	0	0	0
1	4	5	5	5	1
2	8	10	10	10	2
3	12	15	15	15	3
4	13	12	13	14	3
5	9	10	9	12	2
6	5	6	7	4	1
7	1	3	2	1	0
8	6	4	6	7	1
9	2	1	3	2	0
10	14	14	12	13	3
11	10	11	9	8	2
12	11	8	11	9	2
13	15	13	14	12	3
14	3	2	1	3	0
15	7	7	4	6	1

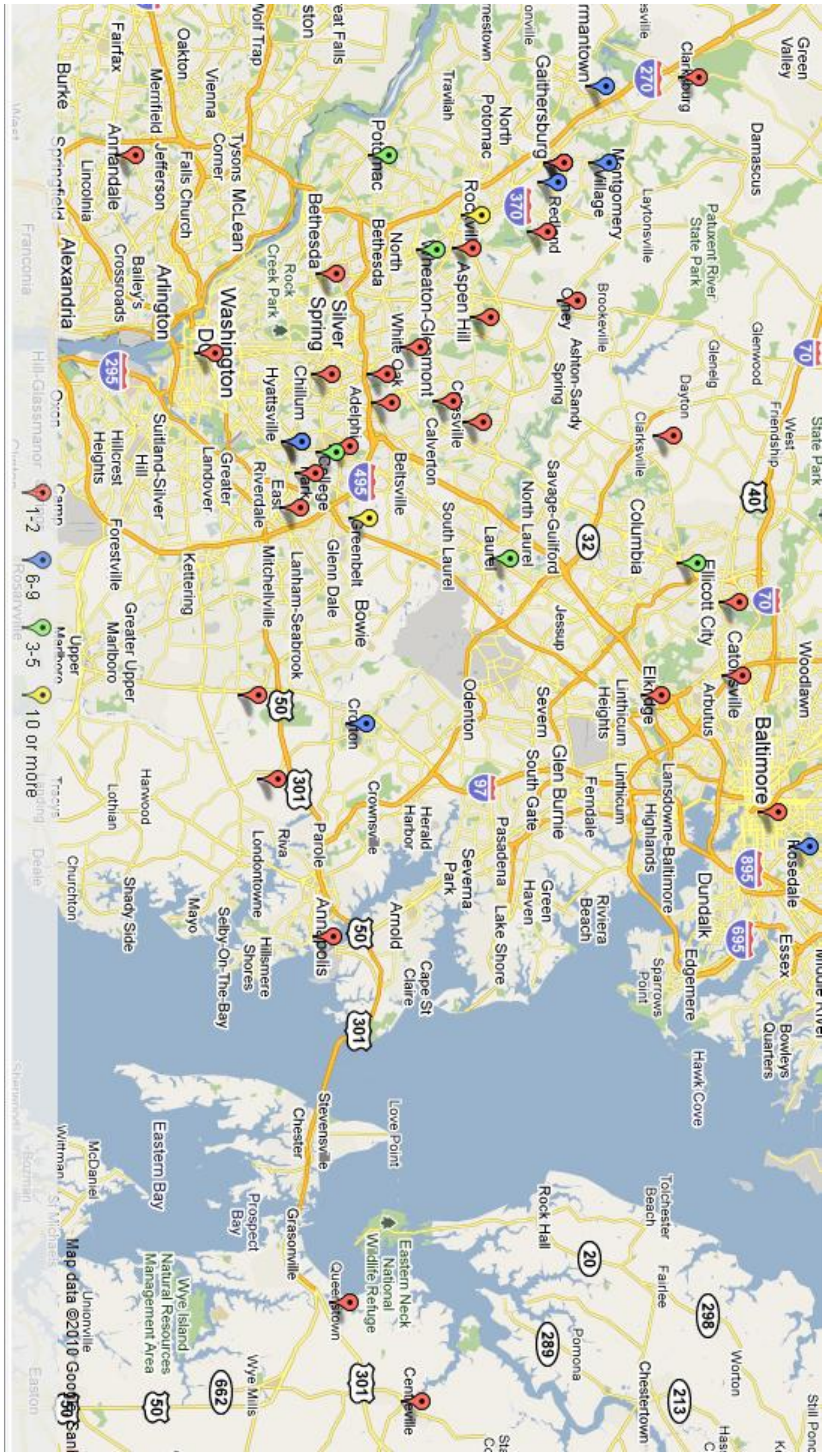
Orthogonal Array for Fuel Technology Game:

Scenario Num	Price	Tax	MPG	Availability
0	0	0	0	0
1	0	1	1	1
2	0	2	2	2
3	1	0	1	2
4	1	1	2	0
5	1	2	0	1
6	1	0	1	2
7	1	1	2	2
8	1	2	2	0
9	2	0	2	1
10	2	1	0	2
11	2	2	1	2
12	2	0	2	0
13	2	1	2	1
14	2	2	0	2
15	2	2	1	0
16	3	0	1	2
17	3	1	1	0
18	3	2	2	1
19	3	0	2	2
20	3	1	0	0
21	3	2	1	1
22	3	2	2	2
23	4	0	1	1
24	4	1	2	2
25	4	2	2	0
26	4	0	0	1
27	4	1	1	2
28	4	2	2	2
29	4	2	0	0
30	5	0	2	0
31	5	1	2	1
32	5	2	0	2
33	5	0	1	2
34	5	1	2	0
35	5	2	0	1
36	5	2	1	2
37	5	0	2	2
38	5	1	0	2
39	5	2	1	0
40	5	0	2	1
41	5	1	0	2
42	5	2	2	1

Orthogonal Array for Taxation Policy Game:

Scenario Num	Deduction	Toll	VMT Tax
0	0	0	0
1	0	1	1
2	0	2	2
3	1	0	1
4	1	1	2
5	1	2	0
6	2	0	2
7	2	1	0
8	2	2	1

Appendix F – Distribution of Households



Glossary

AFV – alternative fuel vehicle, usually refers to a vehicle powered by a fuel that can be used in an internal combustion engine such as ethanol and natural gas.

BEV – battery electric vehicle, a vehicle which runs on electricity stored in on-board batteries. Those batteries are charged from the electric grid.

HEV – hybrid electric vehicle, a vehicle which uses a combination of a gasoline engine and electric motor to propel the vehicle. The operation may be sequential (gasoline engine and electric motor are connected physically) or not sequential (electric motors drive the wheels).

PHEV – plug-in hybrid electric vehicle, a vehicle which operates like an electric vehicle for short distance and a HEV once the stored electricity runs out.

Stated Preference (SP) – the use of hypothetical scenarios to derive a person's preference for products and services; "placing decisions makers in controlled experiments that evaluate hypothetical choices" (Hensher, 2006)

Stated Choice – same as Stated Preference

Choice Set – the set of possible choices a respondent is allowed to make for a choice experiment

Scenario – one possible hypothetical situation shown to respondents, for example it may have situation X, Y, Z and choices A, B, C.

Attribute – characteristics of an alternative which are allowed to vary through the use of different values per level

Variable – same as an Attribute

Stated Preference Game – A set of hypothetical scenarios that share a common choice set, alternatives, attributes, and attribute levels

Choice Experiment – same as Stated Preference Game

Stated Choice Game – same as Stated Preference Game

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