Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SWUTC/09/169202-1		

4. Title and Subtitle Evolution of the Household Vehicle Fleet: Anticipating Fleet Composition, Plug-In Hybrid Electric Vehicle (PHEV) Adoption and Greenhouse Gas (GHG) Emissions in Austin, Texas	5. Report Date December 2009 6. Performing Organization Code
7. Author(s) Sashank Musti and Kara M. Kockelman	8. Performing Organization Report No. 169202-1
9. Performing Organization Name and Address Center for Transportation Research University of Texas at Austin 3208 Red River, Suite 200 Austin, Texas 78705-2650	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 10727
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

Supported by general revenues from the State of Texas.

16. Abstract

Automobile ownership plays an important role in determining vehicle use, emissions, fuel consumption, congestion and traffic safety. This work provides new data on ownership decisions and owner preferences under various scenarios, coupled with calibrated models to microsimulate Austin's household-fleet evolution. Results suggest that most Austinites (63%, population-corrected share) support a feebate policy to favor more fuel efficient vehicles. Top purchase criteria are vehicle purchase price, type/class, and fuel economy (with 30%, 21% and 19% of respondents placing these in their top three). Most (56%) respondents also indicated that they would seriously consider purchasing a Plug-In Hybrid Electric Vehicle (PHEV) if it were to cost $6,000 more than its conventional, gasoline-powered counterpart. And many respond strongly to signals on the external (health and climate) costs of a vehicle's emissions, more strongly than they respond to information on fuel cost savings. 25-year simulations suggest that 19% of Austin's vehicle fleet could be comprised of Hybrid Electric Vehicles (HEVs) and PHEVs under adoption of a feebate policy (along with PHEV availability in Year 1 of the simulation, and current gas prices throughout). In comparison to the base year (2009) total VMT, year 2034 vehicle miles traveled (VMT) levels are predicted to increase 154% by year 2034 in the TREND scenario. Total CO2 emissions fall by 22% in the PRICING scenario relative to the TREND scenario.

17. Key Words	18. Distribution Statement
Vehicle choice, Fleet Evolution, Vehicle Ownership, Plug-In Hybrid Electric Vehicles (PHEVs), Climate Change Policy, Stated Preference, Opinion Survey, Microsimulation	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	165	

Evolution of the Household Vehicle Fleet: Anticipating Fleet Composition, Plug-In Hybrid Electric Vehicle (PHEV) Adoption and Greenhouse Gas (GHG) Emissions in Austin, Texas

by

Sashank Musti
Kara M. Kockelman

Research Report SWUTC/09/169202-1

Southwest Region University Transportation Center
Center for Transportation Research
University of Texas at Austin
Austin, Texas 78712

December 2009

ABSTRACT

Automobile ownership plays an important role in determining vehicle use, emissions, fuel consumption, congestion and traffic safety. This work provides new data on ownership decisions and owner preferences under various scenarios, coupled with calibrated models to microsimulate Austin's household-fleet evolution. Results suggest that most Austinites (63%, population-corrected share) support a feebate policy to favor more fuel efficient vehicles. Top purchase criteria are vehicle purchase price, type/class, and fuel economy (with 30%, 21% and 19% of respondents placing these in their top three). Most (56%) respondents also indicated that they would seriously consider purchasing a Plug-In Hybrid Electric Vehicle (PHEV) if it were to cost $6,000 more than its conventional, gasoline-powered counterpart. And many respond strongly to signals on the external (health and climate) costs of a vehicle's emissions, more strongly than they respond to information on fuel cost savings. 25-year simulations suggest that 19% of Austin's vehicle fleet could be comprised of Hybrid Electric Vehicles (HEVs) and PHEVs under adoption of a feebate policy (along with PHEV availability in Year 1 of the simulation, and current gas prices throughout). In comparison to the base year (2009) total VMT, year 2034 vehicle miles traveled (VMT) levels are predicted to increase 154% by year 2034 in the TREND scenario. Total CO2 emissions fall by 22% in the PRICING scenario relative to the TREND scenario.

EXECUTIVE SUMMARY

In today's world of volatile fuel prices and climate concerns, there is little study on the relation between vehicle ownership patterns and attitudes toward potential policies and vehicle technologies. Improving the fuel efficiency of the future vehicle fleet will provide some opportunity for significant reductions in GHG emissions. But the willingness to adopt new, advanced vehicle technologies, such as plug-in hybrid electric vehicles (PHEVs) and battery EVs (BEVs) can facilitate a shift to domestically produced energy, from non-GHG-emitting sources (including renewables, like wind and solar). This work anticipates the household vehicle fleet evolution, PHEV adoption and its related GHG emissions in Austin, Texas over 25 years.

Automobile ownership choices play an extremely important role in determining vehicle use, vehicle emissions, fuel consumption, highway capacity, congestion, and traffic safety. To accurately forecast future vehicle holdings in order to anticipate emissions, crash counts, gas tax receipts and so forth, planners must have dependable forecasts of vehicle ownership and use. Vehicle fleet evolution and GHG from Austin's personal vehicle fleet were estimated here and the forecasts illuminate several trends and policy possibilities.

Four modeling scenarios are run for fleet composition, vehicle use levels and GHG emissions: TREND (business as usual with $2.50 per gallon fuel price), FEEBATE (progressively higher rebates above 30 mpg and surcharges below 25 mpg), PRICING (a gas price of $5 per gallon) and LOWPRICE (PHEV's costing just $3,900 more than the regular Prius HEV). PHEV adoption is the highest (6.14%) in the reduced PHEV (LOWPRICE) scenario and HEV's share is the highest (14.43%) in the FEEBATE case. Under all scenarios, vehicle usage levels (in total vehicle miles traveled [VMT]) are predicted to increase overall, along with average vehicle ownership levels (per household, and per capita); and a feebate policy is predicted to raise total regional VMT slightly (just 4.43 percent, by simulation year 25), relative to the trend scenario, while reducing CO_2 emissions only slightly (by 3.8 percent, relative to trend). Doubling the trend-case gas price to $5/gallon is simulated to reduce the year-25 vehicle use levels by 17% and CO_2 emissions by 22% (relative to trend). Two- and three-vehicle households are simulated to be the highest adopters of HEVs and PHEVs across all scenarios. A 15% reduction in the usage levels of SUVs, CUVs and minivans is observed in the $5/gallon scenario (relative to trend). In the longer term, gas price dynamics, tax incentives, feebates and purchase prices along with new technologies, government-industry partnerships, and more accurate information on range and recharging times (which increase customer confidence in EV technologies) should have even more significant effects on energy dependence and greenhouse gas emissions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. Mention of trade names or commercial products does not constitute endorseent or recommendation for use.

ACKNOWLEDGEMENTS

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center which is funded, in part, with general revenue funds from the State of Texas. The authors also express thanks to Dr. Randy B. Machemehl and Ms. Annette Perrone, Ms. Emily Wheeler, Ms. Katherine Kortum and Ms. Melissa Thompson for their editorial assistance.

CHAPTER 1: INTRODUCTION

With rapid urbanization, comes a more mobile society (Hao et al., 2006). Increases in U.S. vehicle ownership levels from 1.78 vehicles per household in 1995 to 1.85 in 2001 (NHTS, 2001), accompanied by reductions in average household size from 2.63 persons in 1995 to 2.58 in 2001 (NHTS, 2001) and increases in vehicle trip lengths from 9.06 miles per trip in 1995 to 9.87 in 2001 (NHTS, 2001), suggest that the level of motorization is continuously rising along with increasing demand for gasoline. The U.S. is the world's largest consumer of energy (EIA, 2009) and along with volatile fuel prices and evolving vehicle fleet attributes, concerns about climate change, and national energy security are hot topics of debate, both globally and nationally.

The U.S. contains just 4% of the world's population but produces 25% of all greenhouse gas (GHG) emissions (BBC 2002). The nation's transportation sector accounts for approximately one third of its GHG emissions, two-thirds of its petroleum consumption, and about half of its urban air pollution (NRC, 2006; EPA, 2008). Also, GHG emissions from the transportation sector have increased by 27% between 1990 and 2007 (EIA, 2007). As a result of the nation's increased use of energy-intensive modes of transport, especially private cars and trucks, bus and rail transit now account for less than 3 percent of U.S. passenger travel (Sperling and Lutsey, 2009).

A variety of behavioral changes are expected in coming years, due to volatile fuel prices, new vehicle technologies, and tighter fuel economy policies and other climate change policies. Improving the fuel efficiency of the future vehicle fleet will provide some opportunity for significant reductions in GHG emissions. Americans' willingness to adopt new, advanced vehicle technologies, such as plug-in hybrid electric vehicles (PHEVs) and battery EVs (BEVs) can facilitate a shift to domestically produced energy, from non-GHG-emitting sources (including renewables, like wind and solar). To accurately anticipate future fleet attributes (and therefore emissions, air quality, gas tax receipts, crash counts, and so forth), planners must have dependable forecasts of vehicle ownership (by vehicle type) and use.

This thesis examines opinions on vehicle policy and models the evolution of the household fleet, along with PHEV adoption, over a 25-year period in Austin, Texas. A microsimulation framework based on a set of interwoven models for vehicle ownership and use yields future vehicle composition mix along with GHG emissions forecasts in Austin, Texas.

This thesis is organized as follows. Chapter 2 provides a detailed literature review on vehicle ownership models, electric powertrains, microsimulation models and GHG emissions. Chapter 3 centers on survey design and sample data characteristics, while providing a brief overview of the modeling framework. Chapter 4 compares the simulation results across various policies, and Chapter 5 provides conclusions along with recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Automobile ownership choices play an extremely important role in determining vehicle use, vehicle emissions, fuel consumption, highway capacity, congestion, and traffic safety. Vehicle ownership modeling has a rich history, driven by changing vehicle technologies and volatile oil prices, and the relation of ownership levels to trip generation, mode choice and petroleum consumption. A relatively new, yet crucial, objective of transportation planners and researchers is to know the number and type and use of different automobiles in a community over time. The benefits that a household derives from its fleet depend on use levels, type of vehicles owned, household demographics and other factors. To accurately anticipate future fleet attributes (and therefore emissions, gas tax receipts, crash counts, and so forth), planners must have dependable forecasts of vehicle ownership and use. This chapter reviews the existing literature, with Section 2.2 centering on vehicle ownership and usage models and Section 2.3 presenting a brief overview of electric powertrains. Section 2.4 gives an introduction to microsimulation techniques, and Section 2.5 sheds light on greenhouse gas (GHG) emissions.

2.2 VEHICLE OWNERSHIP MODELS

Much of the existing research on vehicle type choice is based on vehicle attributes, household characteristics, and fuel costs. Manski and Sherman (1976) developed separate multinomial logit models for the number of vehicles owned and the vehicle type for households owning one or two vehicles. This work was one of the earliest efforts to model vehicle type and number of vehicles owned in a single model framework. Lave and Train (1979) controlled for several household attributes, in addition to vehicle characteristics, gasoline prices, and taxes on larger vehicles and found that higher-income households tend to prefer expensive cars and younger individuals prefer high-performance cars. Berkovec (1985) developed nested logit models, with the upper-level nest for number of vehicles and the lower-level nest for vehicle class with vehicle attributes serving as exogenous variables. This disaggregate model of vehicle choice was used to forecast U.S. automobile sales, vehicle retirements and fleet attributes for the 1984-1990 period. Results from such studies highlight the relative importance of capital costs, operating costs, cargo space, and performance on vehicle choice with findings similar to those in Berkovec and Rust (1985), Mohammadian and Miller (2003[a]) and Mannering et al. (2002).

Consumers' travel habits and behavioral attitudes also affect vehicle choice. Choo and Mokatarian (2004) found that travel attitudes, personality, lifestyle, and mobility factors are useful in forecasting the types of vehicles owned within a household and in predicting the most-used vehicle. With a variety of makes and models, fuel type and transmission types available for purchase by consumers, it becomes difficult to estimate a choice model that encompasses all of these variables. Hence, most researchers classify the vehicles into pools based on fuel type, body type, and size (Choo and Mokatarian, 2004). Kurani and Turrentine (2004) found that households purchasing a vehicle do not pay much attention to fuel costs over time, unless they are under severe economic constraints. Factors such as a vehicle's overall visual appeal, its reliability and safety, cabin size, acceleration, purchase price and other amenities were found to have a more significant effect on choice. Similarly, results obtained by Espey and Nair (2005) and Langer and Miller (2008) suggest that consumers value fuel economy and can been seen by monitoring the vehicle purchase behaviors under situations of rising fuel prices.

Gallagher and Muehlegger (2008) studied consumer adoption of hybrid electric vehicles (HEVs) in the U.S. and found that groups with strong preferences for environmentalism and energy security prefer HEVs. Their results show that the combination of rising gasoline prices and social preferences for environmentalism maximizes the sale of HEVs. Nye et al.'s (2003) study revealed that consumers who consider fuel economy during vehicle purchases do so because of budget constraints rather than environmental or energy concerns. Greene (2009) demonstrated that fuel economy is not an important characteristic for vehicle choice because of the uncertainty in the value of expected fuel savings. Greene also claims that most of this uncertainty was not due to volatile oil prices but rather to the variance between the on-road fuel economy and the value quoted.

Larick and Soll (2008) showed that greater benefits could be leveraged from fuel efficient vehicles by highlighting fuel consumption (gallons per mile) rather than fuel economy (miles per gallon). The authors say that vehicle users make incorrect estimations of the value of fuel economy and this affects vehicle choice behavior. Greene et al. (2009) indicate that consumers expect shorter payback periods for purchasing fuel efficient vehicles. The authors point to the fact that consumers' willingness to pay for fuel efficient vehicles is low due to the uncertainty associated with fuel savings and manufacturers would not want to pursue major investments in research and development. The authors recommend that educating the public about possible fuel savings could help reduce the uncertainty.

Consumers' previous vehicle experiences and brand loyalty can also affect choice and use. Extending Dubin and McFadden's (1984) work, Mannering and Winston (1985) employed a dynamic utilization framework for vehicle choice (and use) as a function of the prior year's utilization (a brand loyalty measure), household characteristics, and vehicle attributes. Roy's Identity (Roy, 1947) was used to link an indirect utility function for vehicle choice with vehicle use, measured in annual VMT. A multinomial logit model conditioned on vehicle choice was employed to anticipate the number of vehicles owned. Employing similar models, Feng et al. (2005) studied the effect of gas taxes and subsidies on VMT, vehicle choice, and emissions. As expected, their results suggest VMT reductions, a shift away from SUVs, and greater use of a household's smaller cars under a scenario of higher fuel costs. Hocherman et al. (1983) use an automobile transactions' framework in which households choose whether to buy or sell one or more cars or simply retain their current holdings. Their nested logit specification modeled the decision of whether or not to transact at the upper level, and the decision of vehicle type at the lower level, conditional upon the transaction decision.

The impact of land use variables is also of interest in the consideration of vehicle choice. Train (1980) examined vehicle ownership and work trip mode choices and concluded that households living near their work places or having high access to public transportation will reduce the number of vehicles owned. Zhao and Kockelman (2000) developed a multivariate negative binomial model to predict vehicle ownership by vehicle type. Their results suggest that ownership decisions are firmly related to household size, income, population density (in zone of residence), and vehicle prices. Fang (2008) developed a Bayesian multivariate ordinal response system to model vehicle choice and usage and found higher residential densities to be associated with lower vehicle utilization and fewer light-duty truck holdings, consistent with Zhao and

Kockelman's (2000), and Brownstone and Golob (2009) findings. Bhat and Sen (2006) and Bhat et al. (2008) also conclude that vehicle-holdings and miles of travel vary with demographic characteristics, vehicle attributes, fuel costs, other travel costs and neighborhood characteristics.

Finally, life course events also affect vehicle holdings. Mohammadian and Miller (2003[b]) developed a dynamic transactions model using retrospective panel data collected in Toronto. Their results suggest that recent changes in the number of household workers, adults, driving licenses, and household sizes will prompt acquisition of a new car or replacement of an existing vehicle. Prillwitz et al. (2006) found a positive correlation between vehicle transactions and a change in the number of adults, birth of the first child, change in monthly income, and change in residence.

2.3 ELECTRIC POWERTRAINS

The United Stated Clean Air Act of 1990 required the EPA to enforce gasoline reformulation and tighter air quality standards (EPA, 2008). Reformulated gasoline is estimated to reduce the risk of cancer by 12% and reduce toxic air pollutants by 24,000 tons each year in the U.S., which is equivalent to taking 13 million vehicles off the road (EPA, 1999). Despite the overall increase (12.1%) in the consumption of reformulated gasoline between 2000 and 2008 (EIA, 2009), U.S. GHG emissions from transport increased 27% between 1990 and 2006 (EIA, 2007). As a result, the need to reduce GHG emissions becomes even more dramatic. Improving the fuel efficiency of the future vehicle fleet is one way to tackle emissions. Another approach is to adopt advanced vehicle technologies that rely on fuel produced domestically, and also from non-GHG-emitting sources. Basic definitions of hybrid-electric vehicles (HEVs), plug-in hybrid-electric vehicles (PHEVs), battery-electric vehicles (BEVs) and fuel cell vehicles, all of which would help to achieve the latter approach, are given below.

HEVs integrate a gasoline-powered engine with an on-board electrical energy storage system to deliver motive power to the wheels (Kromer and Heywood, 2007). The internal combustion engines of HEVs run with the help of electric motors and batteries but use gasoline. Even though both systems can be used to run the vehicle, Sperling and Lutsey (2009) say that maximum efficiency come from using the electric motor and battery to eliminate idling, provide regenerative braking and downsize engines.

Unlike an HEV that derives most of its energy from gasoline, a PHEVs uses both gasoline and off-board electricity to deliver motive power. The PHEV draws energy primarily from the battery. Once the battery charge is depleted, it switches to charge-sustaining mode, in which primary energy comes from gasoline (Vyas et al., 2008 and Kromer and Heywood, 2007). A PHEV30 is estimated to have a 30-mile electric range (based on normal use). Overall GHG reductions will depend on distances traveled and the GHG intensity of the electricity used to charge the battery.

BEVs are also known as electric vehicles (EVs). These receive power to drive the vehicle from a battery (off-board electricity) and enjoy a tank-to-wheel vehicle efficiency at least twice that of conventional gasoline vehicles (Sperling and Lutsey, 2009).

Finally, fuel-cell vehicles (FCVs) generate power from the stored hydrogen onboard by using a proton-exchange membrane (PEM) fuel cell (Kromer and Heywood, 2007). These systems enjoy twice the energy efficiency of a conventional ICE and emit GHG's only via the hydrogen production process (Sperling and Lutsey, 2009).

2.3.1 Plug-In Hybrid Electric Vehicles

A PHEV is a mixture of a BEV and an HEV. It provides environmental and energy security benefits like a BEV, but is similar to driving a hybrid-electric vehicle (HEV) in that the range of the vehicle is not limited by battery storage (Kromer and Heywood, 2007). The following review of PHEVs is by no means comprehensive, but instead aims to highlight a few important points that future studies should consider.

Since there are two fuel types (electricity and gasoline) being used, a PHEV operates in two distinct modes (charge-sustaining[1] and charge-depleting[2]). The EPRI (2001) uses Figure 2.1 framework to estimate the fraction of miles drawing power from electricity and from petroleum. Based on the distance at which the PHEV transitions from charge depleting (CD) to charge sustaining (CS) operation, the utility factor (UF) curve provides the utility of the vehicle's CD consumption behavior relative to the CS consumption. The total energy consumption is a function of the utility factor and the energy requirements in the CD and CS modes. This equation comes from Gonder et al. (2009) and is also present in Kromer and Heywood (2007).

$$E_{total} = E_{CD} * UF + E_{CS} * (1 - UF) \quad (2.1)$$

$$UF = \frac{Total\ number\ of\ miles\ driven\ in\ the\ charge\ depletion\ mode}{Total\ number\ of\ miles\ driven} \quad (2.2)$$

where E is the energy consumed and UF is the utility factor.

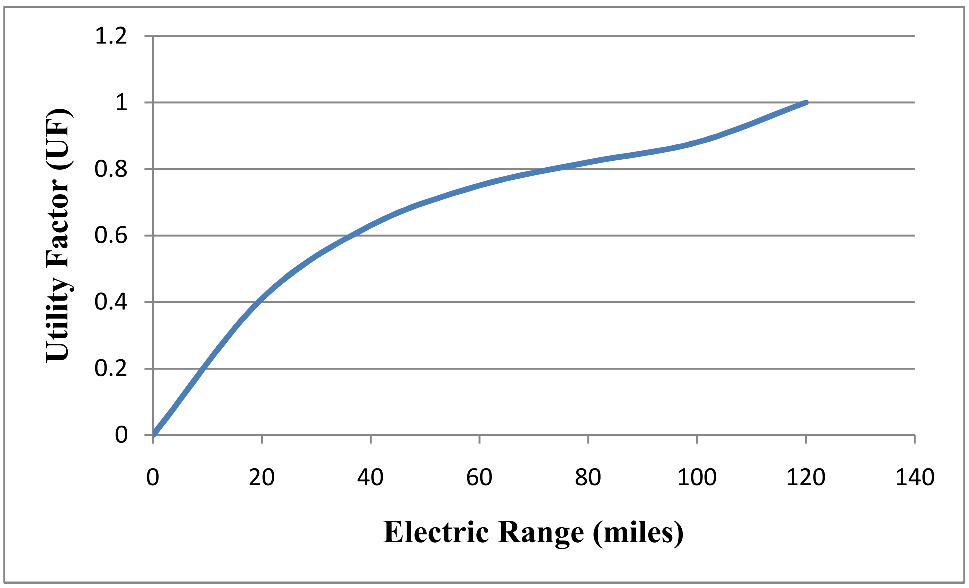


Figure 2.1: Utility Curve for NHTS (2001) Data Set

The utility curve is estimated by dividing daily travel distances into either charge-depleting or charge-sustaining miles. The fractions of miles that are electric are plotted against the different

---

[1]In charge-depleting mode the PHEV relies on electric power from the battery on board until the state of charge on the battery reaches a predetermined level (Simpson, 2006; Markel, 2006; Kromer and Heywood, 2007 and Shidore, 2007).

[2] In charge-sustaining mode the PHEV operates on both power sources, and maintains vehicle efficiency by fluctuating between the two sources. At times it draws energy from the ICE while charging the battery, and then draws exclusively from the battery (Simpson, 2006; Markel, 2006 and Duvall, 2004).

levels of electric range (PHEV-20, PHEV-30, etc.) to obtain the utility curve. This method of estimating the utility factor has been widely employed, including use by Markel and Simpson (2006), Santini and Vyas (2008), Santini (2006), Gonder et al. (2009), Simpson (2006) and Kromer and Heywood (2007). Depending upon the electric range of the PHEV used the fraction of electric and gasoline miles are computed using UF from the curve plotted. The next section highlights the household evolution process, which is an important component of vehicle ownership modeling.

2.4 MICROSIMULATION

Microsimulation can be used to forecast the dynamic state of human behavior by simulating the behavior of each individual or agent in a system. For example, tax policies have been designed by economists using microsimulation models of income structures (Rohaly et al., 2005; Creedy et al., 2005), urban planners have used microsimulation to assess the effects of employment and transportation policy changes (TRIM3, 1997; Zhou and Kockelman, 2006; Zhou and Kockelman, 2008; Zhou and Kockelman, 2010; Waddell et al. (2003) and Tirumalachetty and Kockelman, 2010), and traffic operations software simulates the driver behavior (VISSIM, 1992). Orcutt (1957) appears to be the first to use this framework in a socio-economic context. Increasingly, transportation engineers and planners are using microsimulation techniques to robustly predict human behavior and its effect on various policies.

Since microsimulation involves simulating system behavior via individual agents involved in the system, the most important steps for the process are as follows: develop a data set which emulates the agents currently present in the system, estimate models that determine each agent's behavior and finally, update the decisions and changes in attributes for every agent during each period of interest. Aggregate or disaggregate simulations can be performed to test each of the policies of interest. Transportation planners and modelers need to incorporate the interactions among population processes, the households' long-term choice behaviors, and the economic markets through which households inter act (Kitamura et al., 1996). Agent behaviors need to be modeled endogenously to ensure the distribution of population characteristics are representative at each point of time (Eluru et al., 2008). At an individual level, the choices may be to begin and finish schooling, or to get married or divorced. At a household level, choices include how many vehicles to acquire, how much to use each vehicle, and how long to retain a vehicle. Modeling such decisions at a micro-level is data-intensive and computationally burdensome at times (Vovsha, 2002) as well as quite complex (Goulias and Kitamura, 1992).

Several existing models try to anticipate household travel behavior. These include Bhat et al.'s (2004) A Comprehensive Econometric Micro-simulator for Daily Activity travel Patterns (CEMDAP) to simulate the travel patterns of individuals using an activity-based framework, Miller et al.'s (2001) Integrated Land Use, Transport, and Environment (ILUTE) model an activity-based approach that incorporates supply-demand interactions, and Los Alamos National Laboratory's Transportation Analysis and Simulation System (TRANSIMS) an integrated transportation and air quality analysis tool. GHG emissions estimation is an important part of vehicle ownership modeling; the next section gives a brief discussion of these emissions.

2.5 GREENHOUSE GAS EMISSIONS

The primary GHGs produced by human activities are carbon dioxide (CO2), methane (CH4), nitrous oxides (NOx), and fluorinated gases (EPA, 2007). Vehicle emissions have an impact both at a micro level (pollution that is damaging to human health) as well as the macro level (harming the environment) (Mohammadian and Miller, 2003[b]). A major interest of many regions, agencies, environmentalists, and governments is reducing both vehicle emissions and dependence on fossil fuels. The U.S. Environmental Protection Agency (EPA) provides a general framework for estimating the GHG emissions from vehicle miles traveled using carbon content estimates as per the Code of Federal Regulations. In addition to the GHG emissions listed above, vehicles also produce carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) from the tailpipe, along with evaporative emissions (EPA, 1994). Around 94-95% of the total GHG emissions are CO_2 (EPA, 2005), and one gallon of gasoline produces 19.4 lbs of CO_2 directly, and about 25.4 lbs of CO_2 once upstream (life-cycle) contributions are recognized (EPA, 2007).

There are many tools to estimate vehicle emissions. Some of these include EPA's MOBILE6 software, the California Air Resources Board's EMFAC model and the Oregon Department of Transportation's GreenSTEP (Greenhouse Gas State Transportation Emissions Planning) model.

GreenSTEP is a comprehensive framework to estimate the effect of land use, transportation pricing, and other policies on GHG emissions that includes interactive models of travel and vehicle ownership at the household level (Gregor, 2009). None of these models estimates total life-cycle emissions. Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model, however, does strive to recognize full life cycle emissions, as explained below.

2.5.1 The GREET Model

GREET runs in MS Excel. This tool evaluates life-cycle energy and emission impacts of advanced vehicle technologies and new transportation fuels, from well to pump and pump to wheel, and includes the vehicle's material recovery and disposal (Wang et al., 2007). It allows the evaluation of various vehicle and fuel combinations on a life-cycle basis. Energy use and emission rates are divided into three stages: feedstock (including feedstock recovery, transportation, and storage), fuel (including fuel production, transportation, storage, and distribution), and vehicle operation (raw material recovery and processing, vehicle component production, assembly, disposal and recycling) (Wang, 2007). More than 100 fuel production pathways from various energy feedstocks (petroleum has conventional gasoline, reformulated gasoline, California reformulated gasoline, low-sulfur diesel, conventional diesel, etc.) and 75 vehicle fuel system options (e.g., spark ignition [SI] and compression-ignition direct-injection [CIDI]) are included (Elgowainy, 2007).

In the Well to Pump cycle, default market shares of various fuels are considered, including default data for energy efficiencies and GHG emissions of each of the different fuel production activities (Wang, 2007). User-defined proportions for each fuel production option per simulation year or linearly interpolated shares can also be used (Wang et al., 2007). The oxygen content and sulfur levels can also be defined for each of the different fuels that have an effect on the emissions. Each fuel's transport-related activities are simulated using input parameters, such as transportation modes, transportation distances and energy use intensities (in Btu/ton-mi) across modes.

The vehicle-cycle component, which is a part of the Pump to Wheel model, takes into consideration raw material recovery, material processing, vehicle component production, vehicle assembly, disposal, recycling, fluids (i.e., engine oil, brake fluid, coolant and other regular vehicle operating requirements), and batteries and components such as engine or fuel cell, transmission chassis, motor, generator and body (Burnham et al., 2007 and Burnham, 2007). The Pump to Wheel model uses the Argonne's PSAT model (Rousseau, 2007), EPA's MOBILE 6.2 and the CARB EMFAC model to obtain the fuel economies and then the tailpipe emissions. The default vehicle sub-classes are midsize passenger car, midsize SUV and large pick-up truck. Future vehicle fleet composition is not included in the framework, but GREET has in-built market shares for different fuel type's consumption and hence estimates future emissions from the entire well-to-wheel cycle. Emissions are calculated both for urban emissions (emissions occurring in urban areas) and total emissions (emissions occurring everywhere) for each of the five criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrous oxide (NOx), and particulate matter (PM10 and PM2.5).

Baseline vehicles are spark ignition vehicles fueled with conventional gasoline and/or reformulated gasoline, and compression-ignition direct-injection (CIDI) vehicles fueled with CD and/or LSD. To address the uncertainties involved in many of the input parameters, a stochastic simulation component is also included for better understanding of the results (Subramanyam et al., 2008).

2.6 SUMMARY

The research presented here builds on the extensive existing literature by examining PHEV adoption and household attitudes toward vehicle design and energy policies. In particular, this thesis looks at forward-year fleet-simulation under higher gas prices and feebate policies. Since vehicle ownership is affected by various parameters (including demographics, vehicle characteristics, volatile oil prices, and changes in fuel economy policies), we need to consider the dynamics involved in all of these variables to make robust predictions about the future fleet, use patterns, and GHG emissions.

CHAPTER 3: DATA DESCRIPTION AND MODEL FORMULATION

3.1 INTRODUCTION

A set of meaningful characteristics describing vehicle choice and use was obtained via an Austin-based survey conducted in spring 2009 to anticipate household fleet evolution via transaction and choice decisions. This chapter provides an overview on the acquisition of data, sample data characteristics, and public opinions on vehicle policy. The models estimated and framework employed to understand the evolution of vehicle fleets within and across individual households are also presented.

3.2 SURVEY DESIGN

The Austin based survey was divided into several sections (as shown in Appendix A and http://vehiclesurvey.engr.utexas.edu/). The survey opened with a letter of introduction to briefly explain the purpose for and justification of the study to the respondent, to prepare him/her for the types of questions that will be asked, and to ensure him/her of the strict confidentiality of the data to be gathered. The introductory letter also provided a means of contacting the survey administrator to ask any questions about the survey.

In modeling vehicle ownership, it is important to have information on vehicles that were purchased, leased, sold, scrapped or simply held by a household. Data were collected on Austinites' current vehicle holdings and respondent-estimate usage, type of acquisition, and experience with different manufacturers. Respondents also listed other vehicles they considered when purchasing their last vehicle, noting any important features the rejected vehicles lacked. The survey included questions on respondents' previous vehicle ownership, including prior year vehicle miles traveled (VMT), timing of acquisition, and reasons for letting go of the vehicles. One potential disadvantage to asking respondents for past history is its reliance on a person's ability to remember the past clearly enough to give accurate responses. However, since the purchase or other acquisition of automobiles, is a pretty major event for most households (second in expenditures only to home or boat purchase, for example), it was reasoned that most details would be remembered. Also, respondents' were asked about their most likely transaction decision in the coming 12 months (for example, whether the person was planning to buy, sell or do nothing with his or her current household fleet).

Vehicle preferences are also important in anticipating future vehicle purchase behavior. Under the assumption that a vehicle had to be acquired, respondents were asked to select one of twelve new vehicles they would buy or lease under four different scenarios. The options were randomized across scenarios and across respondents. Images for each vehicle, purchase prices and informative links for each vehicle model (to www.edmunds.com) were provided. In the first scenario, the 12 alternatives were accompanied by fuel economy and purchase prices. The 12 vehicles included a wide spectrum of available vehicles, ranging from very low to very high fuel economy, and low to very high purchase prices. The vehicles encompassed all major body types: compact (Honda Civic), subcompact (Toyota Yaris), large (Nissan Maxima), and luxury cars (Lexus ES 350); a minivan (Honda Odyssey); a pickup truck (Ford F-150); two cross-over[3]/sport utility vehicles (Nissan Murano and Ford Escape); a Prius hybrid electric vehicle (HEV); a Prius plug-in HEV (PHEV); a Mercedes Smart Car and a Hummer. Information from Kurani et al. (2009), Axsen and Kurani (2008), Markel (2006a), Markel (2006b), and CalCars.com was used to estimate the PHEV's effective fuel economy and purchase price. Assumptions include a 30-mile all-electric range (PHEV30) requiring about 250 watt-hours per mile, with an 11-gallon gasoline tank, resulting in a total range over 500 miles. All other attributes of the PHEV30 matched a Toyota Prius[4].

The second and third scenarios featured the assumption that gas prices would stabilize around \$5 and \$7 per gallon, respectively. Respondents were asked to choose the vehicle they would most likely purchase, if they had to purchase one, using the information provided on purchase prices and annual fuel costs for driving 15,000 miles. In the final (fourth) scenario, estimates of the monetary value of global warming and health costs of each vehicle, from driving 15,000 miles each year, were presented for each of the 12 vehicles. These external costs for most vehicles were taken from Lemp and Kockelman (2008), but estimates had to be created for the PHEV

[3] CUVs are vehicles that borrow features from SUVs but have a car platform for lighter weight and better fuel efficiency.

[4] The Chevrolet Volt (BEV) should be launched in 2010 (according to www.chevrolet.com). Prius PHEVs are expected by 2011 (Sperling and Lutsey, 2009), but some Prius HEV owners have modified their vehicles to charge from home now (Kurani et al., 2009).

option, using Small and Kazimi's (1995) morbidity and mortality costs by pollutant type and the U.S. EIA's estimates of pollution from electricity generation for the Texas state (EIA, 2002). Concerns about PHEV battery disposal were also taken into consideration during this calculation. First Electric Coop (2009) and CalCars.com indicate that the new lithium battery's disposal should not pose an environmental issue. Thus, the climate and health cost of driving a PHEV30 15,000 miles a year was expected to range from just $65 to $95 (depending on whether users drive 7 days per week or just 5 days per week). In contrast, the Mercedes Smart Car was estimated to impose an annual external cost of $300[5] and the Hummer $965 per year. Calculations for these costs can be found in Appendix B.

The next set of questions sought respondents' attitudes toward various policies and engine technologies that encourage higher fuel economies. For example, it asked about the willingness to support a feebate policy, as well as their opinion on the acceptance of fuel efficient vehicles. Such results are useful in guiding policy decisions, in terms of anticipating public support or concerns.

The final section of the survey sought demographic information, including the respondent's age, household size, income, worker-student status and home location. These allow for more meaningful regression model specifications, to get at many of the core reasons for differences in vehicle purchase and use decisions. Sections 3.2 and 3.3 of this chapter discuss the survey's distribution and collection of the data, which are challenging tasks when survey budgets are very limited, as they were here.

3.3 SURVEY DISTRIBUTION

The survey was web-based to manage the cost of distributing the survey widely in the Austin area. Web-based surveys have several advantages relative to other options. For example, they facilitate design flexibility while speeding data assembly and reducing acquisition costs, and they

---

[5] The high externality cost for the Smart Car is due to the electric power range requiring about 35.5 watt-hours per mile (www.fueleconomy.gov).

have the potential to better represent one's target population (Smith et al. 2009a)[6]. Internet usage rates in the U.S. have increased from 44% in 2000 to 74% in 2009 (Internet World Stats, 2009), and concerns of biased coverage were also tackled by estimating weights to reflect Austin's general population (as explained in section 3.4.1). Neighborhood associations and 160 community organizations (from the regional transit agency and the University of Texas to the lesser-known Austin Pug Club society) were contacted to broadcast the survey link through their networks. In addition, 650 respondents to an earlier energy survey (Musti et al., 2009) agreed to be contacted via email for this related survey.

3.4 DATA DESCRIPTION

This section of the report presents descriptive statistics (weighted and unweighted) for responses to several important questions. Non-response is a very common and important problem in surveys that do not carry incentives. Approximately 690 surveys of the 1350 submitted surveys were partial responses and could not be used for data analysis. The sections below describe in detail the data-weighting procedure, geo-coding framework, and data statistics.

3.4.1 Weighting

Weights were estimated to better reflect the true Austin population. Sampling weights were assigned to each record in the data set according to each respondent's demographic representation in the 3-county population, based on the 2000 Public Use Microdata Sample (PUMS), as described below. Some records did not have all desired demographic information to weight properly. The initial sample size (of nearly complete responses) was 660, but only 645 could be assigned weights. 15 records were lacking some of the demographic information used to compute the weights (due to item non-response) and so were left out of data analysis.

To reflect Austin demographics, weights were developed by first dividing the sample set into 720 categories (in a multi-dimensional space). These divisions were based on gender (male, female), age (six categories), worker status (worker, non-worker), student status (student, non-

[6] Smith et al. (2009a) collected travel data using multiple recruitment methods at once, in various U.S. locations, and found that those responding via the Internet did not differ from the general population in any significant way. In fact, in certain dimensions Internet respondents can be more representative than those electing other response methods.

student), and household size (1, 2, 3, 4, 5+). Household income categories of low (<$30,000 per year), medium ($30,000 to $75,000) and high (>$75,000) were also employed using the 2000 Census's 5% PUMS. Cells in the multi-dimensional space that housed zero counts (in either the sample or PUMS data sets) were merged with adjacent cells. Ratios of census-to-sample counts were then normalized, resulting in 645 usable records.

3.4.2 Geo-Coding

Once all the questionnaires were received, respondent addresses were geo-coded using TransCAD (Caliper Corporation, 2002) and matched to Austin's database of traffic analysis zones (TAZs). The questionnaire requested home addresses, but not all of the respondents provided usable location information. Presumably to preserve privacy, some respondents provided only zip codes, which could not be linked to a particular TAZ. Others left the question entirely blank. Unfortunately, addresses along relatively new streets also could not be found using TransCAD. Due to non-response, response error, and other matching issues, only 608 (94% of the 645 weighted records) were geo-coded to a TAZ.

Supplementary data sets were prepared for the three-county Austin region using Capital Area Metropolitan Planning Organization's (CAMPO's) land use data for the year 2000 and CAMPO's 1997 road network. These datasets provide variables such as household and population counts; developed land per TAZ (in acres); household, population, and neighborhood densities; employment counts (by industry sector); and network distances to the region's Central Business District (CBD), the UT campus, and Austin airport at the TAZ level of resolution. Based on this data, each geo-coded survey record could be assigned land use attributes for the respondent's home location.

3.4.3 General Observations

As Table 3.1 suggests, household sizes match the 2000 Census demographic averages. However, women are under-represented and working households are over-represented. The sample is also biased towards more educated people, with 84% of the respondents holding a bachelor's degree or higher, as compared to the Census average of 40% for the Austin area. This high level of education is also reflected in the sample's very high mean income of $80,368, which is notably higher than the Census average of $47,212. The average number of vehicles per household in the sample is 1.71, which is lower than the Austin average of 2.34[7]. Fortunately, the appropriate weighting of each record in the dataset ensures that relatively unbiased survey results and estimated regression model parameters can be relayed.

Table 3.1: Summary Statistics for Sample Demographics (Unweighted)

Variable	Minimum Value	Maximum Value	Average Value	Standard Deviation	Census 2000 Average
Household Variables					
Number of vehicles	0	6	1.706	0.96	2.34
Maximum age of vehicle in household (years)	0	36	6.21	5.07	--
Household size	1	7	2.246	1.265	2.40
Number of workers	0	5	1.577	1.47	0.87
Age (years)	20	70	37.13	15.08	29.6
Female indicator	0	1	0.358	0.480	0.510
Household income ($/year)	5,000	200,000	80,368	56957	47,212
Income per person (household income / household size, $1,000)	1.25	200	38.17	26.39	--
High income household indicator (income of household greater than $80,000)	0	1	0.4503	0.4976	--
Household size greater than 5 indictor	0	1	0.0488	0.2155	--
Location Variables					
Urban indicator	0	1	0.2104	0.4078	--
Suburban indicator	0	1	0.3184	0.4601	--
Vehicle Characteristics					
Fuel cost ($/mile)	0.0543	0.1667	0.1057	0.0374	--
Purchase price ($)	15,000	61,500	28,500	12,184	--
Transaction Decision (in the coming year)					
Acquire	0	1	0.2214	0.4155	--
Dispose	0	1	0.0511	0.2203	--
Do nothing (neither acquire nor dispose)	0	1	0.7276	0.4456	--

[7] Vehicle ownership statistics come from the 2006/2007 Austin Travel Survey.

Figure 3.1 summarizes weighted responses for vehicle preferences under different scenarios. When information on each alternative's fuel economy and purchase price was provided, the most popular choices were the compact car and HEV options (a Honda Civic with 26% of votes and the Toyota Prius with 20%). Under the gas price scenarios of $5 and $7 per gallon, the Toyota Prius and PHEV Prius were the most popular choices. At $5/gallon they received 27% and 15% of votes, respectively; at $7/gallon they received 27% and 29% of votes, respectively. Interestingly, less than 6% of (weighted) respondents stated a willingness to purchase an SUV, a CUV, or a minivan in all four scenarios (Figure 3.1). While this set of shares are not consistent with past purchase patterns by Ausinites' (the 2006/07 Austin Travel Survey shows a model year 2003 through 2006 household fleet that is 14% SUVs, 4% CUVs and 9% minivans), it may be that recent gas price spikes and the global recession are causing shifts in purchase decisions.

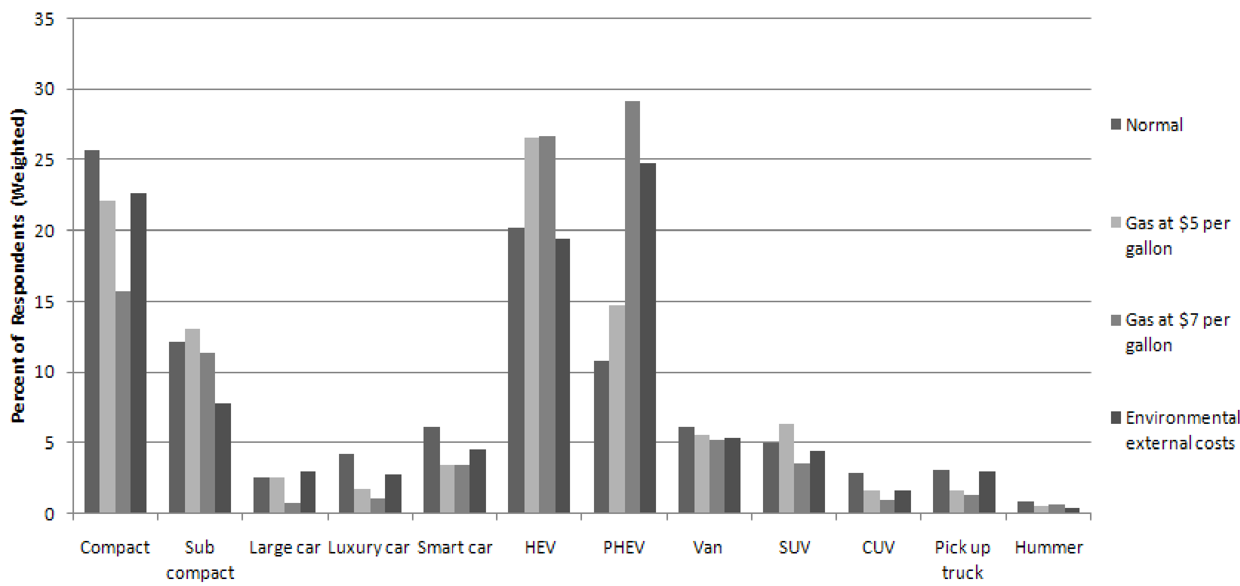


Figure 3.1: Vehicle Selection Shares across Different Scenarios (Weighted Responses)

Figure 3.2 indicates the top three attributes that buyers look for when seeking a new vehicle. Purchase price (30%) was the most popular choice, but fuel economy (28%) and reliability (21%) are also key characteristics for Austinites. In fact, fuel economy is top rated when one considers how many buyers list this attribute among their top-three criteria: It enjoys 76% of the (weighted) vote, versus 74% for those listing purchase price in the top three and 54% for reliability. While Austinites are known for their progressive ways and high level of education (see, for example, opinion surveys on transport topics by Smith et al. [2009b]), these results are not necessarily inconsistent with findings by Greene (2009), Espey and Nair (2005), Langer and Miller (2008) and Turrentine and Kurani (2004). Their pointed examinations of vehicle choice vis-à-vis fuel economy caused them to conclude that households neglect much future gasoline-related savings when evaluating the effective purchase price of a vehicle (unless severe economic constraints exist). In fact, as shown later, a logit model for vehicle preferences does not enjoy a statistically significant coefficient on fuel economy, so some neglect of fuel costs in final choice is apparent, even in this sample. In fact, the model results here suggest an effective discount rate of well over 30% per year (in order to equate $1 in the present valuation of likely gas savings to $1 in purchase price). 30% applies only at an unusually low 5,000 miles-travelled-per-year assumption. At 10,000 miles per year, the implicit discount rate is a whopping 102%.

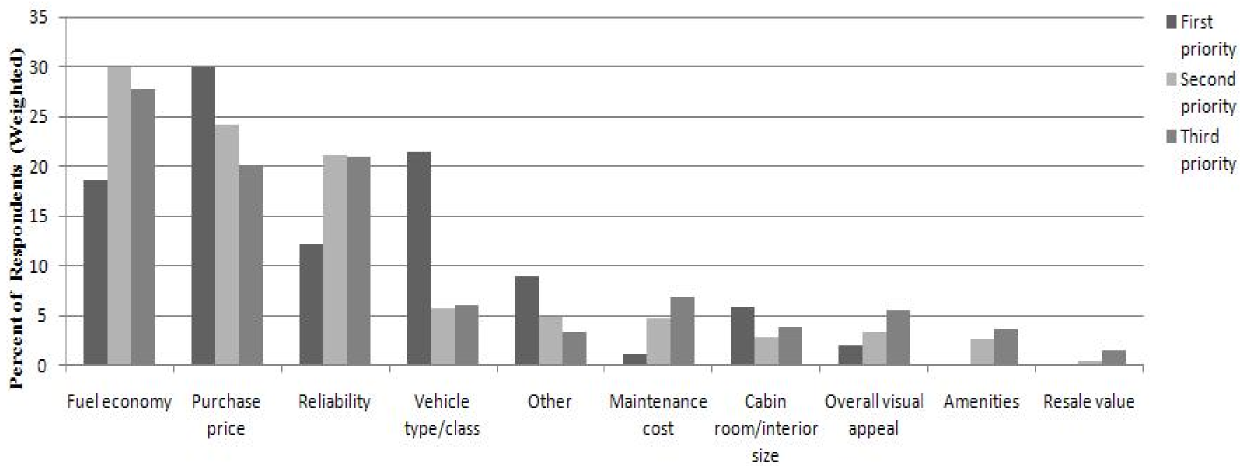


Figure 3.2: Top Three Attributes for Vehicle Selection (Weighted Responses)

Another interesting feature of the simple responses, as given directly in the data set, is support for proposed policies. The majority of respondents (Figure 3.3 shows 63%, population-weighted) indicated support for a feebate policy (on the sale of vehicles), with vehicles over 30 mi/gal fuel economy enjoying a rebate, and those under 30 mi/gal paying a premium. (The survey form indicated, for example, a $3,000 rebate on 40+ mi/gal vehicles, versus a $1,000 fee for 25 mi/gal vehicles and a $4,000 fee for those averaging 10 mi/gal or less.) 56% of respondents indicated that they are ready to purchase a PHEV, even if it costs $6,000 more than its conventionally fueled counterpart. Related to this, 55% of the weighted respondents reported that they have access to electricity in their garage or a carport near their residential unit. This is very consistent with Axsen and Kurani's (2008) recent survey result, that 52% of new vehicle buyers in the U.S.

have convenient access to a home outlet for PHEV recharging. Appendix C contains the summary responses from the questionnaire.

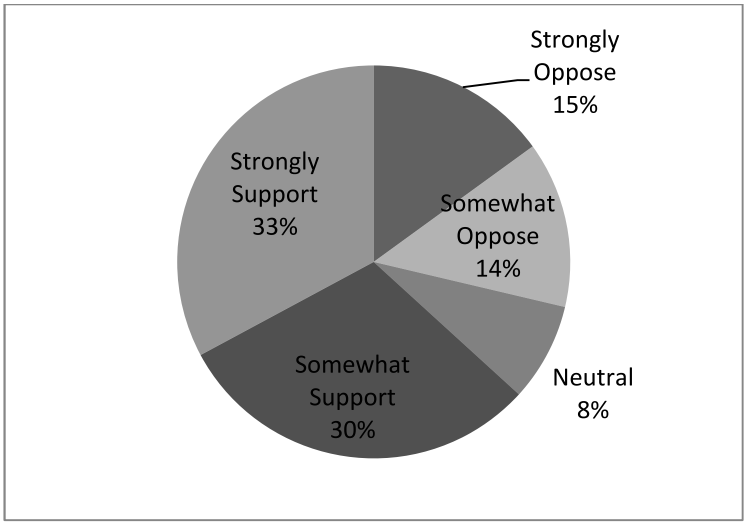


Figure 3.3: Responses to the FEEBATE Policy (Weighted Responses)

Figure 3.4 illustrates respondent opinions toward a $6 per gallon gasoline price. 39% of (population-weighted) respondents indicated that they would adapt to the change. Figure 3.5 provides a more detailed explanation on the ways in which respondents would adapt.

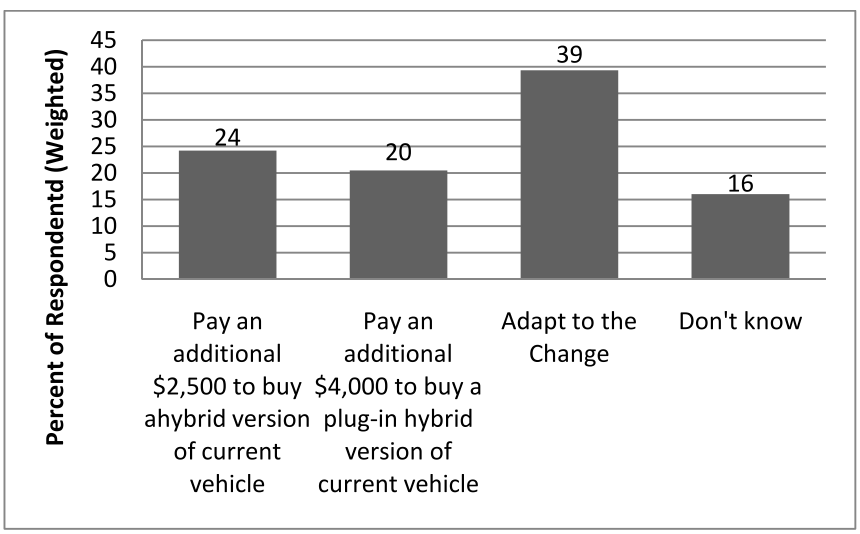


Figure 3.4: Responses to the $6 per Gallon Gasoline Price (Weighted Responses)

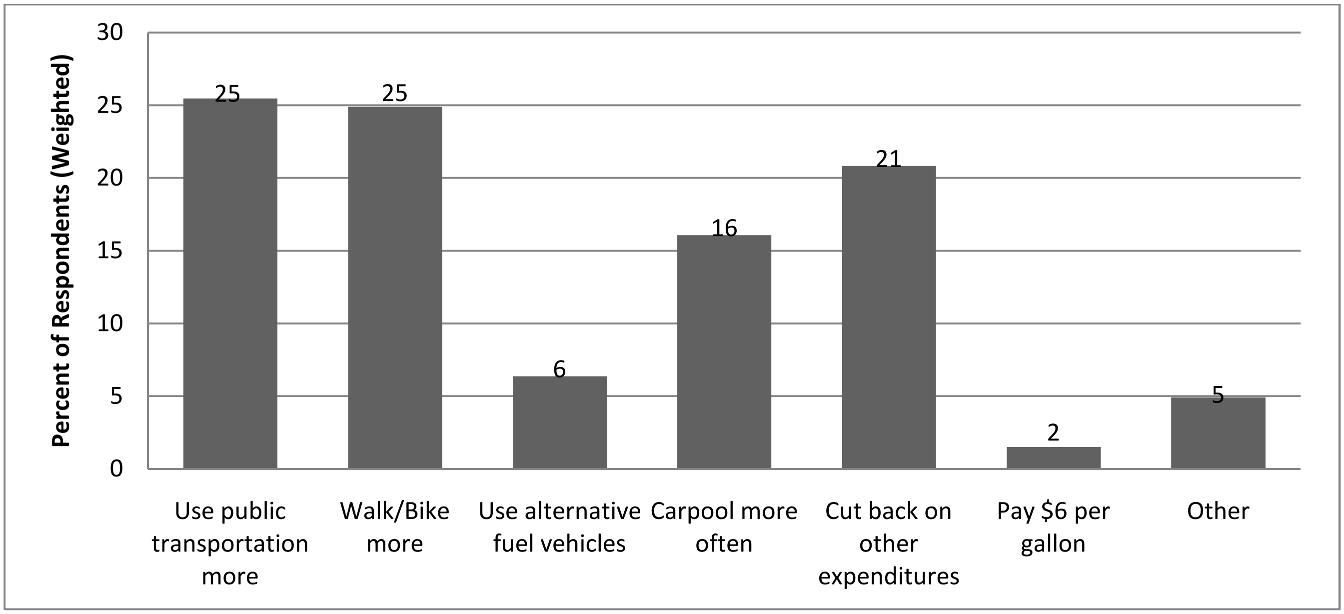


Figure 3.5: Price Adaptation Strategies (Weighted Responses)

3.5 MODELING FRAMEWORK

Figure 3.6 displays the modeling framework used in the study. The aim of the study is to make long-term forecasts over a 25-year period (from 2009 through 2034). A microsimulation framework based on a set of interwoven models for vehicle ownership and use seeks to mimic the evolution of vehicle fleet, as shown in Figure 3.6.

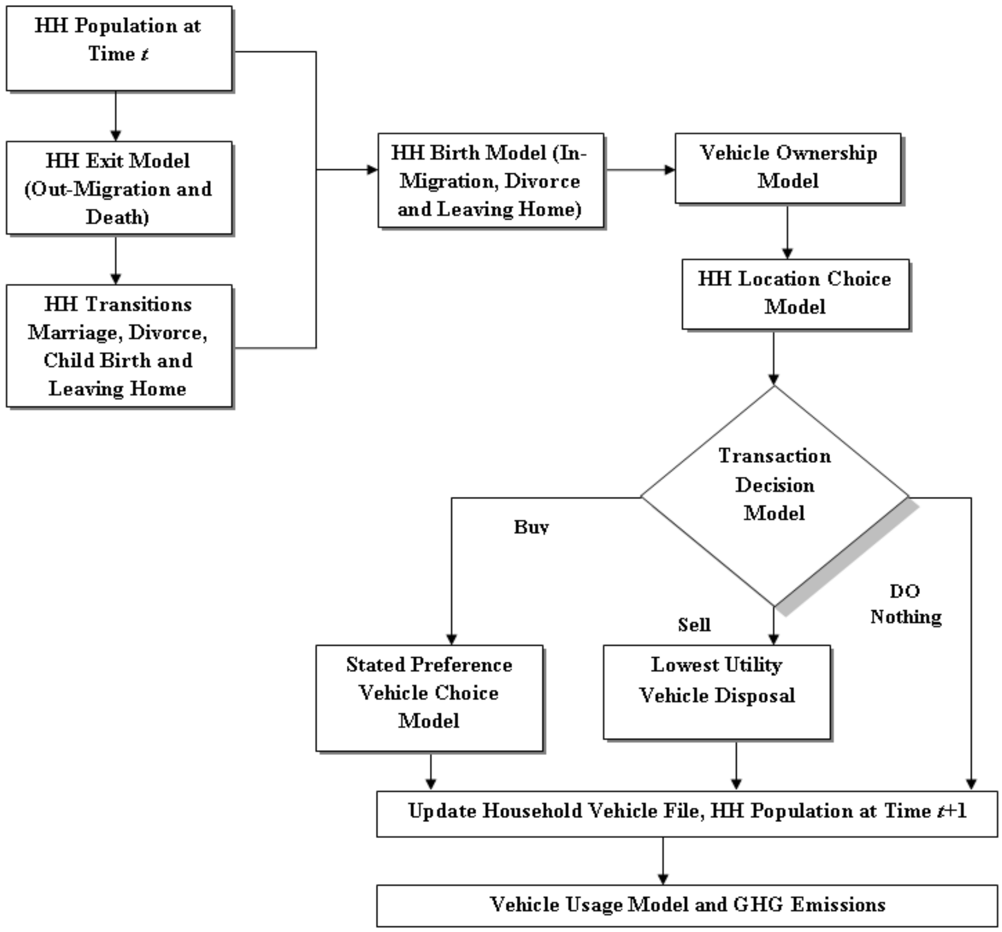


Figure 3.6: Overall Simulation Framework

Cross-sectional datasets from the 2000 Census, our Austin Vehicle Choice survey (Spring 2009), and GIS archived data on Austin's land uses were used to model various discrete processes to help attain the final result. The next section talks about household data sets and the models that have been estimated using them. The subsequent sections present details of the models for vehicle ownership, vehicle choice, vehicle transactions, vehicle usage and GHG emissions estimation.

3.6 HOUSEHOLD DATA SETS

The base year synthetic population was estimated by McWethy (2006). Pre-school children, pre-driving school-age children, driving school-age children, non-working adults, student adults, part-time and full-time working adults are the seven different person types selected for analysis. While McWethy's data set was developed for Austin's 2005 population, the base year of this simulation is assumed to be 2009 (so the population count is biased somewhat low).

Sub-models for simulating the household and individual evolution process were taken from various studies. Kumar (2008) developed models for birth (of children and of households), death of individuals (and other forms of household dissolution), migration, and young adults leaving home. Model results from Tirumalachetty et al. (2009) and Tirumalachetty (2009) for new residential development in Austin coupled with Bina and Kockelman's (2006) household location choice model were used for household demographic evolution and locations across TAZ's. Because of the dynamics involved in household demographics and residential location choices which influence vehicle choice and use decisions over time. Model estimations from other studies were used in the framework. More details about the data sets used and model specifications utilized can be found in Tirumalachetty and Kockelman (2010), Tirumalachetty (2009), Kumar (2008), and Bina and Kockelman (2006).

3.7 VEHICLE FLEET EVOLUTION

While straightforward weighted averages of survey results are one way to utilize the data, multivariate relationships exist, and these associations inform models of who is likely to do what and when. Here, a microsimulation of vehicle holdings is based on a set of interwoven models with annual transitions. The first stage of the microsimulation is the annual application of a vehicle transactions model that simulates the decision to acquire, dispose of or keep a vehicle (in each year). Monte Carlo methods (for the associated multinomial logit specification) are used to ascertain the choice of each household. In the case of a "buy" decision, the stated preference vehicle choice probability of purchase by vehicle class determines the type of vehicle class acquired by the household (again using Monte Carlos methods). Due to the low number of stated choices for the Hummer among the 12 stated vehicle choice alternatives, the Hummer vehicle class was clubbed in the CUVs class during model estimation. In the case of a "sell" decision, vehicles with the lowest systematic utility[8] (within a selling household) were identified and removed. In the "do nothing" case, all vehicles were retained.

[8] Table 3.4's vehicle ownership model determines the systematic utility of each vehicle in a household.

Several different model specifications were explored, including a variety of interaction effects (across covariates). The final specifications were obtained based on a systematic process of eliminating variables that did not show statistical significance (at the 95% confidence level). Yet variables enjoying meaningful practical significance were kept in the model specification, even if they had t-statistics near 1.0 (or p-values up to 0.34). For example, employment and population densities were regularly removed, due to very low t-statistics, while indicators for rural, suburban and urban areas (which are based on job-equivalent densities[9]) were often retained, with t-statistics around 1.2. These results are presented in subsequent sections.

3.7.1 Data Description

Vehicle choice and auto ownership levels in a household were modeled using responses from the Vehicle Choice Survey conducted as part of this research project. *Ward's Automotive Yearbook* (2007) was used to extract data on vehicle attributes specific to make and model, and these were averaged by class, as shown in Table 3.2. Vehicles were classified on the basis of body type, size and function into nine categories: (1) luxury cars, (2) large cars, (3) midsize cars, (4) subcompact cars (5) compact cars, (6) pickup trucks, (7) sports utility vehicles (SUVs), (8) cross-over utility vehicles (CUVs), and (9) vans (minivans and cargo vans). Unfortunately, HEV, PHEV and Smart Car attributes are not available in *Ward's Automotive Yearbook* (2007), but their attributes were obtained via other sources as mentioned in Section 3.2.

As expected, compact and subcompact cars (small cars) have the highest average fuel economy and the lowest average area (length times track width) and weight. Pickups, SUVs and vans have lower fuel economy values, in comparison to the other vehicle classes, and therefore lower GHG scores[10]. Identification of such vehicle attributes or parameters are important for model specifications and estimations.

---

[9] The thresholds are defined in Zhou and Kockelman (2008)and are based on a combination of employment and household density values- with thresholds of 8, 3 and 1 person-equivalents per acre for urban, suburban and rural area respectively.

[10] EPA (2008) classifies GHG scores in intervals ranging from 0 to 10 based on the amount of CO_2 emissions per mile (depends on the fuel economy) from a given vehicle make and model.

Table 3.2: Summary of Vehicle Characteristics

Vehicle Class	Fuel Economy (mpg)	Average Purchase Price ($)	Area (square feet)	GHG Score (EPA ratings)	Weight (lbs)
Compact cars	20.65	29576.5	84.12	6.31	3187
Subcompact cars	26.6	16726.4	82.94	7.7	2640
Large cars	17.57	30734.2	105.11	5.51	3825
Luxury cars	18.61	48004.8	94.01	5.5	3696
Midsize cars	19	25614	95.65	6	3416
Pickup trucks	14.67	26825.4	115.13	3.83	4741
CUVs	18.08	26932.3	92.04	5.63	3837
SUVs	15.1	35221.2	104.65	4.04	4621
Vans	15.18	27411.4	110.55	4.64	4540

3.7.2 Model for Number of Vehicles in a Household

Figure 3.3 gives the distribution of vehicle ownership levels in the sample. Nearly 50% of the households have exactly one vehicle, while 33% have two vehicles. Almost 3% of Austin households do not own a vehicle.

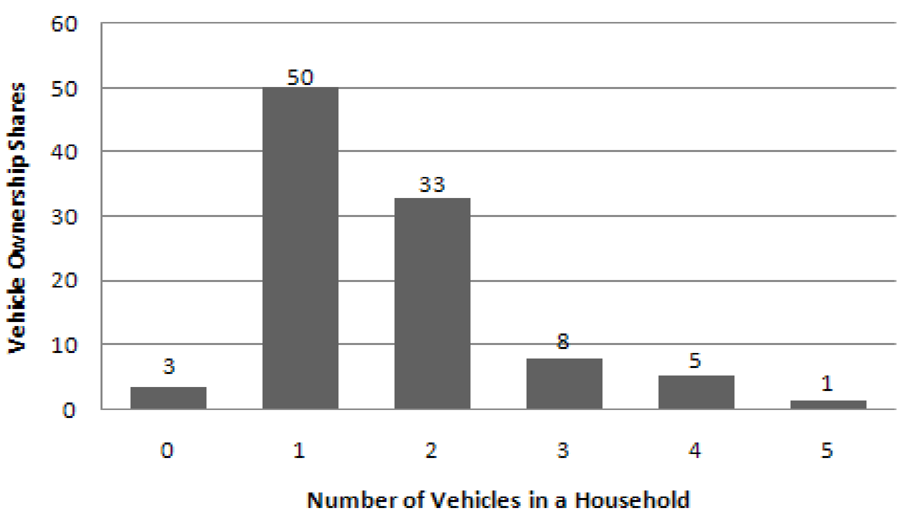


Figure 3.7: Vehicle Ownership Levels in Austin (2009)

To estimate vehicle ownership levels, negative binomial and Poisson count model specifications were used, with the results supporting the simpler, Poisson specification (The over-dispersion parameter of the negative binomial model was found to be statistically insignificant.). Table 3.3 gives the results of the vehicle-ownership count model, where the response variable is the number of vehicles held by each household in the 2006/2007 ATS data set. This model's results were then used to estimate vehicle ownership levels for all households in the base year (2009) of the simulation.

Table 3.3: Poisson Regression Model for Number of Vehicles in a Household

Independent Variables	Coefficient	T-statistic	Mean Elasticity
Constant	-0.1572	-1.29	-
Household Size	0.03949	2.75	0.1002
Income per person (total income/household size)	1.82 E-06	1.30	0.0684
Age of respondent	2.50 E-03	1.17	0.0970
Own home	0.3619	4.45	0.2360
Region-Specific Variables			
Distance to CBD	9.50 E-03	1.68	0.0544
Job density (jobs per acre in TAZ)	-4.00 E-03	-1.54	-0.303
Log Likelihood at Convergence	-946.9		
Pseudo R^2	0.0300		
Number of observations	1,500		

Note: Elasticities were evaluated at each record's attributes and then averaged, to provide a mean elasticity across households.

As income per person rises, ownership levels also rise. This result is intuitive because it speaks to the higher disposable income of the respondents. Home owners also tend to own more vehicles than renters, everything else constant, and this indicator variable registers as the second most practically significant of all covariates. The most practically significant is job density, with a striking elasticity value of -0.303: as job density doubles, vehicle ownership levels may fall by 30 percent, suggesting that density (or the attributes for which it proxies, such as regional access, central location, and land use balance) could have significant benefits for reduced vehicle and energy use in this country.

Additionally, as distance to the CBD falls, the number of vehicles falls, providing a type of "double dividend" since a high share of jobs are centrally located (53% jobs centrally located). These results complement Fang's (2008) recent findings and those of Zhao and Kockelman (2001), which suggest that population density (at the home zone) is practically (and statistically) significant in vehicle ownership decisions. Using a panel data set from Germany, Prillwitz et al. (2008) described the impact of changes in demographic attributes, such as the birth of a first child or an increase in household income, associated with increased car ownership. The authors also suggest that the relocation of households from a central area to another central area appears to cause a decrease in car ownership.

3.7.3 Vehicle Ownership Model

While this following model specification is based on the current vehicle holdings in the Austin data set and thus does not indicate current purchase preferences for future vehicle holdings, it based on revealed behaviors and thus serves as a useful counterpart to the stated-preference model results, as discussed below. Table 3.4 presents the results from a multinomial logit model for each vehicle held (by class) for the data set's 608 vehicle-holding households. (These 608 households own 1002 vehicles, so the number of observations is 1002.)

Table 3.4: Model Estimates for Vehicle Ownership (Weighted)

Variable	**Coefficient**	**T-Stat**
Fuel cost	-8.514	-2.83
Purchase price x 10^{-5}	-5.570	-3.94
Age of respondent less than 30 indicator x Midsize car	0.3627	2.28
HHsize greater than 4 indicator x SUV	0.8756	3.41
HHsize x Van	0.2895	4.66
Crossover utility vehicle	-0.4148	-2.43
Luxury car	-1.1210	-3.51
Suburban x SUV	0.2632	1.32
Urban x Midsize car	0.1864	1.21
Log Likelihood at Constants	-1455.2	
Log Likelihood at Convergence	-1443.0	
Pseudo R^2	0.0846	
Number of observations	1002	

Data on 2007-model year purchase price, engine size, and fuel economy were obtained for each household vehicle from Ward's Automotive Yearbook (2007). Mid-size cars accounted for 32% (unweighted[11]) of all vehicles owned by survey respondents. Other passenger cars (luxury, large, compact, and sub-compact) constitute another 32% (unweighted) while minivans, SUVs, CUVs and pickups constitute the remainder.

[11] Unweighted results are shown in Figure 3.8 because the market shares forecasted by the revealed preference vehicle choice model will follow similar trend as depicted in the figure.

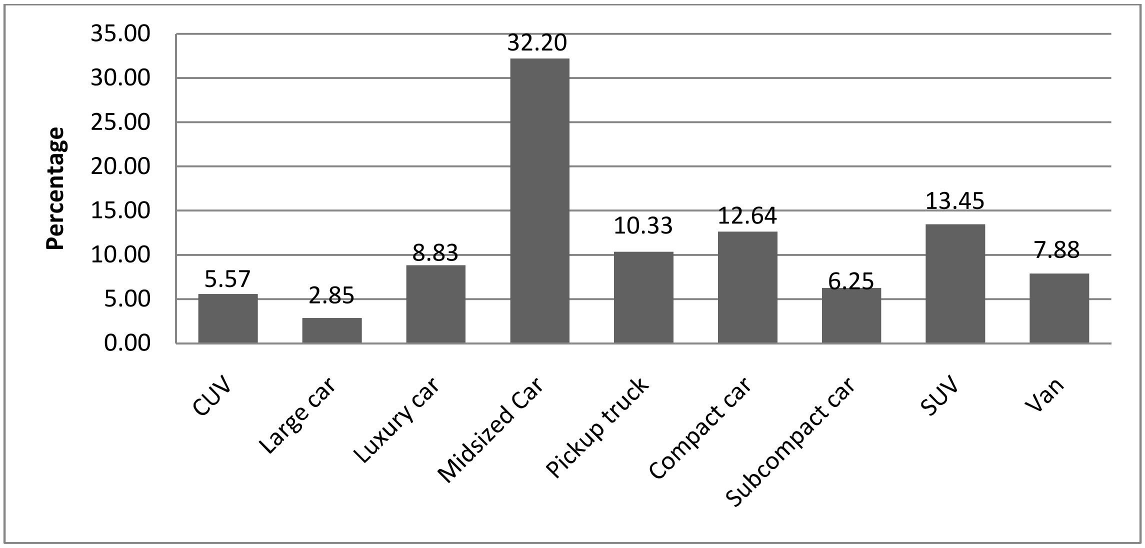


Figure 3.8: Vehicle Class Shares in the Vehicle Choice Survey (Unweighted)

The capital costs (purchase price) and fuel costs (in dollars per mile) are statistically significant in Table 3.4's results, and both enjoy negative coefficients˜ as expected and consistent with earlier findings (e.g., Lave and Train, 1979; Mannering and Winston, 1985; Berkovec and Rust, 1985; Mannering et al., 2002). Younger respondents (under 30 years of age) have a tendency to hold midsize cars, perhaps as a vehicle handed down by parents or purchased used. (51.9% of the mid-size cars are in the data set were reported as being acquired used, versus 55% across all held vehicles in the data set). Larger households have a preference for SUVs and vans, likely due to such vehicles' larger seating capacities and cargo space. The base preference for luxury cars and CUVs (as exhibited by alternate specific constants for these two categories) is low, as compared to other vehicle classes.

Land use characteristics of home location are associated with vehicle choices as well. Those living in surburban areas are more likely to acquire SUVs, whereas those in urban zones appear more attracted to mid-size cars, everything else constant. Finally, results show that higher purchase prices coupled with high fuel costs lead to a lower utility of a vehicle.

3.7.4 Vehicle Choice Model (Stated Preference)

Table 3.5 presents the results from the multinomial logit model for stated preference vehicle class choice. Here, all vehicles offered in the survey can be classified into the above-mentioned nine classes, or special categories for a Prius HEV and PHEV, and Mercedes Smart Car. Data on

2009 model year purchase prices and fuel economies were obtained for each specific vehicle option from www.edmunds.com (2009). In the base-case choice experiment, compact and sub-compact cars accounted for 36% of the selections (population weighted) while the HEV and PHEV drew 23% and 9% of selections respectively. Mid-size cars only recorded 7% of the vote while representing 31% of current vehicle holdings, signaling a potential shift to smaller cars and more fuel efficient vehicles.

The coefficient on purchase price enjoys very high statistical (and practical) significance, while that on fuel costs ($/mile) does not, even though 76% of respondents stated that fuel economy is within their top three criteria for vehicle purchase. This result is consistent with the findings of Kurani and Turrentine (2004), Small and van Dender (2007) and Puller and Greening (1999). Fuel cost was removed from the model specification because its t-statistic was just -0.72.

Interestingly, combining the stated choices over the first three scenarios presented to respondents' (with information presented on fuel economy and purchase price, annual fuel costs for driving 15,000 miles at $5/gallon and purchase price, and annual fuel costs for driving 15,000 miles at $7/gallon and purchase price, respectively) resulted in a very high statistical significance for the fuel cost parameter. This result indicates the significance of labeling and advertising fuel expenditures ($'s) rather than fuel economy.

The results also suggest that even though larger households prefer vans and are less likely to select the HEV, they exhibit a statistically significant and positive attitude towards PHEVs, perhaps for commute-use reasons. High-income households also exhibit a preference for PHEVs; such households may have the ability to pay more for environment friendly alternatives. Model results also suggest that higher-income households tend to purchase more light duty trucks, SUV, and CUVs, presumably because they can afford the generally higher ownership and operating costs.

Interestingly, younger respondents appear less likely to select HEVs, PHEVs, and Small Cars. While not so intuitive, this finding is consistent with earlier work (Choo and Mokatarian, 2004; Kitamura et al., 2000). Women appear to be significantly more likely to select HEVs than compact cars, which may be due to safety and reliability concerns. Persons living in suburban areas are more likely to acquire vans, ceteris paribus, whereas those in urban zones appear to prefer PHEVs. This result may be due to wider streets in suburban settings along with easier parking conditions and longer travel distances where interior comfort for passengers becomes more important.

As the number of vehicles in a household increases, the preference for owning a PHEV is reduced. Interestingly, fuel economy is not found to be statistically significant, which implies that consumers may not truly prioritize fuel savings (at least not in this stated choice experiment). It may also simply signal high degree of collinearity in retained variables (like purchase price and vehicle type). Purchase price and the household status (income, household size, age) do have a significant effect on vehicle type/class purchase.

Table 3.5: Model Estimates for Vehicle Choice (Weighted)

Variable	Coefficient	T-Stat	Re-estimated ASC's
Sub compact	-1.9590	-8.76	-2.544
Luxury	2.1810	4.94	2.284
Smart Car	-2.1410	-9.54	-2.440
HEV	1.0060	4.48	0.971
SUV	-1.3760	-6.45	-0.711
PHEV	2.5940	4.82	2.283
Compact	--	--	-2.211
Large	--	--	1.051
Van	--	--	-0.236
Purchase price x 10^{-4}	-2.7170	-9.99	--
HHsize greater than 5 indicator x PHEV	0.4520	1.35	--
HHsize greater than 5 indicator x HEV	-1.6900	-2.69	--
HHsize greater than 5 indicator x Van	1.8790	6.04	--
High income indicator(>$80k) x PHEV	0.7990	2.66	--
Income per member x (Smart Car, Sub-compact, Compact, Large cars) x 10^{-5}	-2.3500	-2.48	--
Age of respondent x (HEV, PHEV, SUV, Compact, Sub-compact)	0.0446	2.85	--
Number of vehicles in a household x Van	0.1765	1.30	--
Number of vehicles in a household x PHEV	-0.4660	-2.26	--
Number of vehicles in a household x Pickup truck	-0.6682	-2.83	--
Female indicator x HEV	0.4355	1.88	--
Female indicator x Compact car	-0.5422	-2.55	--
Urban indicator x PHEV	0.8118	2.60	--
Suburban indicator x Van	1.1849	4.14	--
Log Likelihood at Constants	-1083.7		
Log Likelihood at Convergence	-1072.8		
Pseudo R^2	0.1635		
Number of households	553		

As noted earlier, the (stated preference) vehicle choice model's predicted shares do not match the profile of recent model year vehicles in the 2006/2007 ATS. Subcompact and compact cars are over-predicted by the model, while SUVs, CUVs and pickup trucks are under-predicted. The difference between predicted and base shares for subcompact was 6%, compact cars was 22%, CUVs was -2%, SUVs was -5%, and pickup trucks was -17%. Hence, alternate specific constants (ASCs) were re-estimated (as shown in Table 3.4's final column) to ensure that the predicted market shares match newer-vehicle ownership patterns in the Austin Travel Survey (i.e., model years 2003 through 2006). Stated choice shares for the newest vehicle types (HEVs, PHEVs and Smart Cars) were preserved, and squared differences between predicted and target market shares were minimized to generate the 9 ASCs.

3.7.5 Vehicle Transactions Model

The frequency and nature of vehicle transactions are critical to fleet evolution. As vehicle attributes and household status change over time, a household's vehicle fleet changes. Respondents provided information on their past and likely future transaction decisions and it is this future intention that is modeled here. The alternatives are to buy a vehicle, sell a vehicle, or do nothing (neither buy nor sell) in the next 12 months. About 22% of the respondents indicated their intent to buy a vehicle, 5.2% planned to sell their vehicle, and the rest (72.8%) expected to simply hold their current fleet (i.e., do nothing). Giffin and Miller (2009) of R. L. Polk find that the average length of ownership of a new car or truck is about 56 months while that of new and used vehicles increased from 37 in 2002 to 46 months in 2008 (Goebel, 2009).The U.S. was in (and continues to be in) a recession at the time of this survey, so fewer households may actually acquire another vehicle in the coming year than respondents stated in the survey. Either way, these survey proportions are reasonably close to those in Roorda et al.'s (2000) and Mohammadian and Miller's (2003) revealed-choice results, where 80% of respondents kept their vehicle fleet constant in any given year, 12% replaced a vehicle (bought and sold in same year), 7% simply bought a vehicle and 1% disposed of a vehicle. Table 3.5 presents the model estimates.

As shown in Table 3.6 the number of workers in a household is estimated to have a positive effect on acquisition, while the number of vehicles held has a positive effect on disposal; both of these results are rather intuitive. Women appear more likely to want to retain current vehicles; but, as household income increases, households are more likely to acquire and/or dispose of a vehicle, which is intuitive. Model results also suggest that older vehicles are held for longer durations.

Table 3.6: Multinomial Logit Model Estimates for Vehicle Transaction by a Household in a Given Year (Weighted)

Variable	Coefficient	T-Stat
Acquire	-1.8314	-7.33
Dispose	-3.7824	-8.96
Number of vehicles in the household x Dispose	0.4077	2.44
Number of workers in a house x Buy	0.2507	2.31
Female indicator x (Acquire, Dispose)	-0.3303	-1.79
Maximum age of vehicle in household x (Acquire, Dispose)	-0.0955	-4.63
Income of household x Do nothing	-2.25E-06	-1.33
Log Likelihood at Constants	-505.37	
Log Likelihood at Convergence	-448.65	
Pseudo R^2	0.3679	
Number of households	640	

Note: Base transaction is to hold vehicle another year.

Using respondents' previous vehicle history, a binary probit model was estimated to determine if the vehicle acquired was likely to be new or used. About 44% respondents indicated their most recent vehicle acquisition to be a new vehicle, while 40% bought used vehicles from used car lots or via-newspaper advertisements, and the rest (16%) acquired their used vehicles from family or friends. Table 3.6 presents the results of this model.

Table 3.7: Binary Probit Model Estimates for Newness of Vehicle in Most Recent Vehicle Acquisition (Weighted)

Variable	Coefficient	T-Stat
Constant	-0.1956	-1.30
Household size	0.1257	2.98
Number of workers in the household	-0.3385	-5.01
Number of vehicles in the household	-0.2294	-3.17
Income of household	5.15E-06	4.26
Maximum age of vehicle in household	0.0564	4.23
Log Likelihood at Constants	-405.36	
Log Likelihood at Convergence	-376.52	
Pseudo R^2	0.0712	
Number of households	585	

Note: 1 if most recent vehicle acquisition was a new vehicle; and 0 otherwise

3.7.6 Vehicle Usage Model

The vehicle usage model is estimated using the National Household Travel Survey (NHTS) 2001 sample, because VMT data collected in the Austin survey yielded adjusted R^2 values of just 0.02.

Outliers in the data set were removed from analysis, and the natural logarithm of VMT was used as the response variable (to ensure non-negative predictions while moderating heteroskedasticity at higher levels of household VMT). As expected, income, household size, and lower density settings (i.e., rural area households) are associated with higher VMT, thanks to longer trip distances and/or greater trip making engagements. The directionality of these results is in line with Kockelman and Zhao (2000) analysis of vehicle VMTs in the 1995 NPTS. Intuitively, fuel cost has a negative effect on annual VMT. This effect is similar to the results obtained by Small and Dender (2005). In general, results are as expected, with the vehicle's age variable offering the greatest practical significance (as measured by elasticity), followed by fuel cost and number of workers in a household.

Table 3.8: Annual VMT per Vehicle

Variable	Coefficient	T-statistic	Mean Elasticity
Constant	9.492	74.65	-
Income of household	9.13E-07	3.29	0.0553
Household size	0.0193	5.81	0.0525
Number of workers	0.0575	12.28	0.0889
Age of vehicle (years)	-0.0217	-26.45	-0.1489
Age of vehicle (years) * Pickup truck indicator	0.0014	1.46	0.0098 (with respect to Truck indicator)
Population density per square mile	-6.40E-06	-7.33	-0.0208
Rural indicator	0.1194	13.21	0.0304
Fuel cost (cents/mile)	-0.0229	-22.05	-0.1334
Fuel cost (cents/mile) * Minivan indicator	8.25E-03	8.88	0.0111 (with respect to Van indicator)
Fuel cost (cents/mile)* SUV indicator	7.76E-03	10.25	0.0154 (with respect to SUV indicator)
R^2	0.1302		
Adjusted R^2	0.1296		
Number of observations	16,248		

Note: Dependent variable is Ln (VMT) from the NHTS 2001 data. Elasticities for VMT were evaluated with respect to each record's attributes and then averaged, to provide a mean elasticity across households.

3.8 SUMMARY

This chapter highlighted the microsimulation framework used to track each household in the Austin region. A discussion of different models developed for vehicle ownership and usage was provided including information on strengths and weaknesses. A few key points to note are that demographic variables such as household size, number of workers and income have an impact on auto ownership, type of vehicles owned and usage levels. Of course, vehicle characteristics, such as age of vehicle, fuel economy and purchase price have an effect on annual VMT and/or purchase decisions. In addition, a household's neighborhood attributes appear to play a significant role in number of vehicles held (after controlling for household size and income, and respondent age, for example). The next chapter describes the results of the model application in the Austin region.

CHAPTER 4: SIMULATION RESULTS AND DISCUSSION

4.1 INTRODUCTION

Microevolution of all sampled households was undertaken using yearly transitions and MATLAB code (MathWorks, 2007) that can be found in Appendix D. This chapter discusses the results of the vehicle evolution process under the various scenarios investigated in this study. The Capital Area Metropolitan Planning Organization (CAMPO) region (Figure 4.1) is made up of three counties (Travis, Williamson and Hays) spread over 1,074 traffic analysis zones (TAZs). In the model application, households and their vehicle fleet were evolved by applying the sub-modules discussed in Chapter 3 using Monte Carlo methods.

4.1.1 Scenario Development

Four scenarios were used to forecast changes in vehicle ownership, fuel consumption and GHG emissions. These are a trend scenario (TREND), the implementation of a feebate policy (FEEBATE), the implementation of a gas tax (PRICING), and a reduced or "optimistic" plug-in hybrid electric vehicle (PHEV) pricing policy (LOWPRICE).

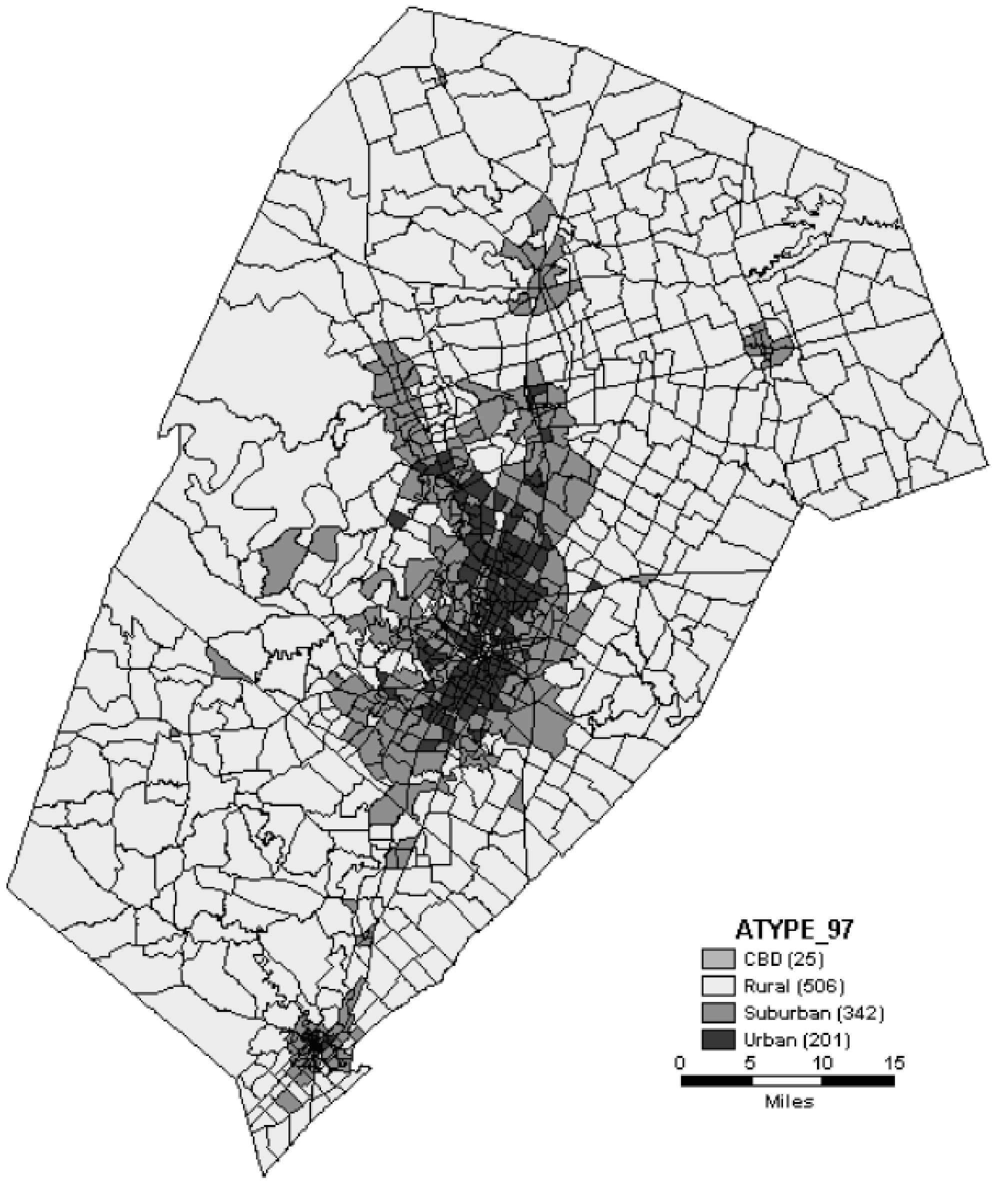


Figure 4.1: Three-County Austin Region (TAZs by Location Type)

In the base scenario (TREND), no changes were made to the base year assumptions, which include PHEVs costing $8,000 more than the comparable HEV and gas price being held at $2.50 per gallon over 25 years. This scenario serves as a baseline or trend case for comparing the results across remaining scenarios. In the feebate scenario (FEEBATE), vehicle purchasers, irrespective of vehicle class receive rebates if they purchase vehicles with a relatively higher fuel economy, while those who purchase less efficient vehicles are surcharged. Studies by Greene et al. (2005) and Train et al. (1996) reveal that fees and rebates should be implemented based on vehicle class with different pivot points. The mechanism of the rebate/fee used in this study is as follows: Those who purchase a vehicle with a fuel economy above 40 mpg would receive a rebate of $3,000, a fuel economy between 35 and 40 mpg would receive a rebate of $2,000, a fuel economy between 30 and 35 mpg would receive a rebate of $1,000, a fuel economy between 25 and 30 mpg would receive no rebate or fee, a fuel economy between 20 and 25 mpg would have to pay a fee of $1,000, a fuel economy between 15 and 20 mpg would have to pay a fee of $2,000, a fuel economy between 10 and 15 mpg would have to pay a fee of $3,000 and a fuel economy less than 10 mpg would have to pay a fee of $4,000. In the third scenario (PRICING), gas prices were set to $5 per gallon (rather than $2.50 per gallon). In the last scenario (LOWPRICE), the PHEV would cost $3,900 more[12] than a regular Toyota Prius Hybrid, according to Sperling and Lutsey's (2009) discussions.

Figure 3.6 shows the overall simulation framework. Vehicle fleet composition and household population were assumed to evolve independently. Meanwhile, vehicle usage models were coupled with the other models to obtain simulated fuel consumption levels and GHG emission levels. Detailed estimates of household attributes, vehicle fleet composition, location patterns, and greenhouse gas estimates are provided in the next section.

4.2 HOUSEHOLD EVOLUTION

A full household evolution simulation for ten percent of the three-county population (52,399 households) took 2 days on a 3GB RAM personal computer with a 2.4 GHz processor, just to obtain the region's future demographics mix. The code to do this came from Tirumalachetty (2009). Vehicle fleet composition and usage models were then run to the get the required results, and these required 10 hours per scenario on the same machine. All the estimated results are scaled up by a factor of 10, to try and reflect the Austin population over a 25-year period. Table 4.1 shows population attributes for the simulation period (2009 through 2034) and can also be found in Tirumalachetty (2009) till the year 2030. Mean household income during the period of interest increases steadily, at an average of 1.1% per annum, while average household size falls by 3.3% between 2009 and 2034. The directionality of these results is in line with the statistics

[12] A PHEV Toyota Prius would cost $28,900 instead of $33,000.

provided by NHTS (2001). The number of households and persons are simulated to grow by 109% and 70%, respectively, over the 25-year period.

Table 4.1: Forecasts of Population Attributes over Time

	Year 2009		Year 2015		Year 2020		Year 2025		Year 2030		Year 2034	
No. of households	523,990		626,800		717,110		865,440		944,600		1,010,720	
No. of persons	1,295,990		1,529,520		1,568,930		1,706,720		2,085,710		2,425,730	
	Mean	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
Household size	2.48	1.43	2.44	1.30	2.38	1.23	2.41	1.35	2.44	1.41	2.40	1.42
Household income	$55,400	$48,637	$57,257	$54,243	$57,337	$53,159	$58,341	$50,876	$58,067	$52,341	$58,475	$51,500
Pre-school age children indicator	0.15	0.36	0.17	0.37	0.15	0.36	0.15	0.35	0.15	0.35	0.16	0.38
Pre-driving children indicator	0.23	0.42	0.20	0.40	0.18	0.38	0.16	0.36	0.15	0.36	0.17	0.33
Driving age children indicator	0.06	0.24	0.05	0.22	0.05	0.21	0.04	0.20	0.04	0.19	0.02	0.18
Non-working adults indicator	0.20	0.4	0.18	0.39	0.18	0.38	0.17	0.37	0.16	0.37	0.14	0.35
Student adults indicator	0.15	0.35	0.14	0.35	0.14	0.35	0.14	0.35	0.14	0.35	0.15	0.35
Part-time working adults indicator	0.34	0.47	0.30	0.46	0.28	0.45	0.26	0.44	0.24	0.43	0.24	0.40
Full-time working adults indicator	0.68	0.47	0.65	0.48	0.64	0.48	0.62	0.49	0.61	0.49	0.59	0.48

4.3 EVOLUTION OF VEHICLE FLEET

This section describes the household fleet simulation results, which are a wholly new contribution of this work, taking off from the synthetic households in each year of the simulation period. Vehicle ownership and household/population characteristics were updated at the end of each 1-year time-step of the simulation model. The following discussion focuses on the base year's vehicle ownership profile. Figures 4.2 and 4.3 show ownership levels over the entire population and average ownership levels per TAZ for the 2009 base sample.

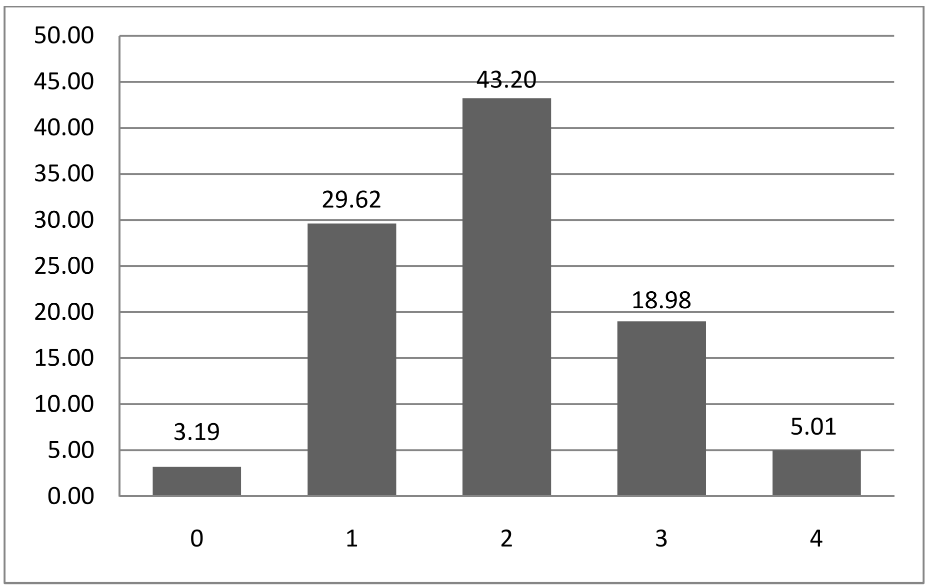


Figure 4.2: Vehicle Ownership Levels (Base Sample)

One can see that many centrally located zones tend to have auto ownership levels below the mean. 51% of the zones in Austin have above average vehicle ownership levels, as evident in Figure 4.3.

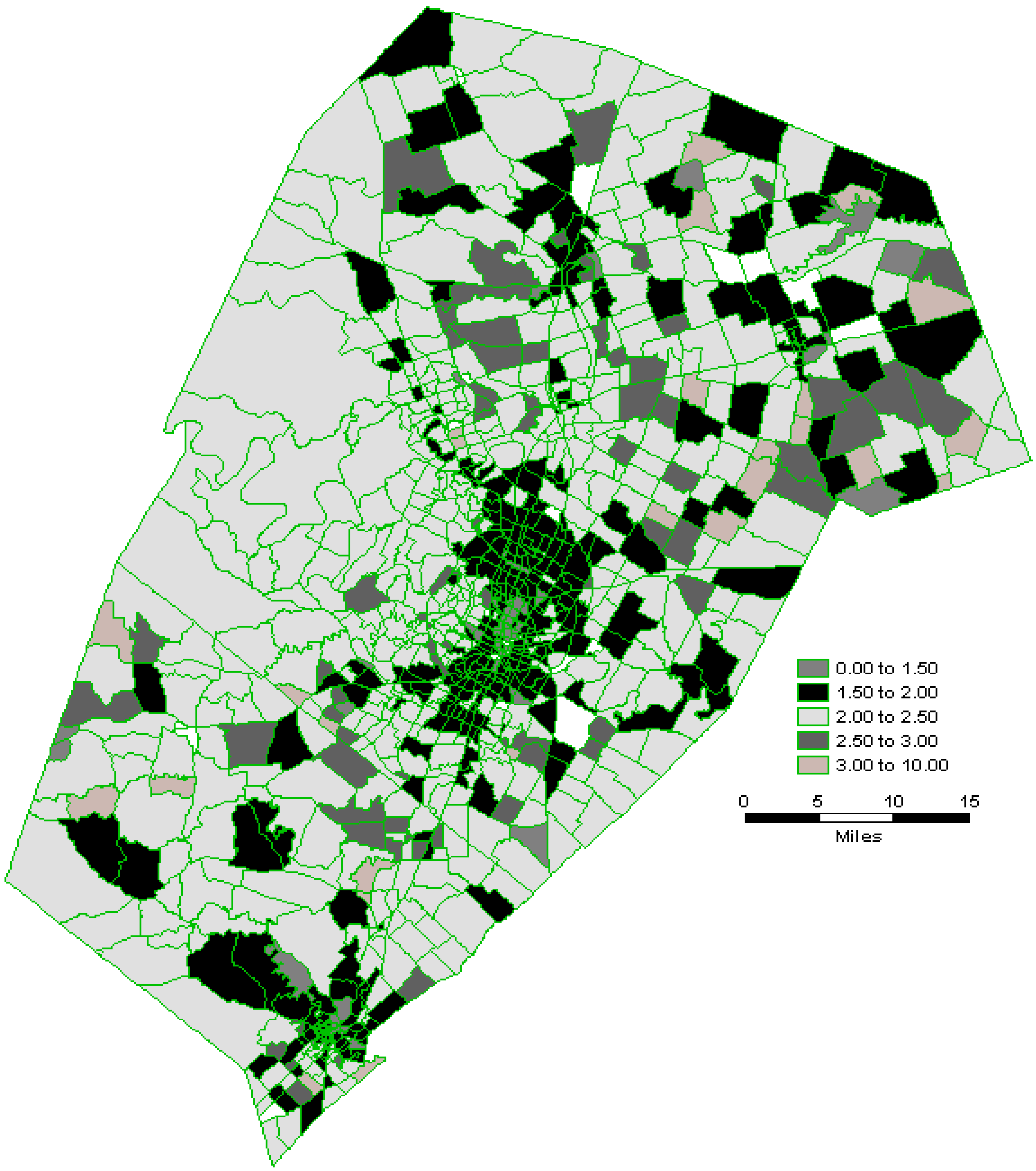


Figure 4.3: Average Vehicle Ownership Levels (Base Sample)

Tables 4.2 through 4.5 illustrate the simulated vehicle ownership patterns and composition profiles over time, under various scenarios. These scenarios imply somewhat different vehicle purchase and use costs, which served as covariates in the models, thus resulting in different probabilities of purchase (and disposal). Results suggest a steady increase in auto ownership levels over time, in line with the results obtained by the NHTS (2001), Tirumalachetty et al. (2009), and Tirumalachetty and Kockelman (2010). A constant fall in the shares of CUVs, mid-sized cars and subcompact cars held by Austin area households is also evident. This trend can be attributed to the rise in ownership levels of HEVs, PHEVs and SUVs, which have similar body type, appearance and performance measures.

In the 2008 IEA report on the future of hybrid and road electric vehicles, HEVs are estimated to represent 2.2% of all year-2008 car sales. According to the results of this thesis' modeling, the share of HEVs and PHEVs will represent 10% of the overall household fleet by 2034, if assumptions of gas and vehicle prices and demographics hold, along with base-year vehicle and climate regulations. These results are in line with the IEA's (2008) recent report that the lack of public awareness regarding alternative-fuel vehicles, the reluctance shown by vehicle manufacturers, and conflicting interests of the government and vehicle buyers is likely to leave market shares of HEVs and PHEVs in the single digits through 2015. The IEA (2008) also stated that the market for battery electric vehicles is small, and acceptance of two-wheeler electric vehicles might prepare the market for advanced electric-powered designed vehicles. Table 4.2 presents the overall mix of Austin's future vehicles under the **TREND scenario**.

Table 4.2: Fleet Composition under Trend Scenario (TREND)

	Year 2009		**Year 2015**		**Year 2025**		**Year 2034**	
	Count	%	Count	%	Count	%	Count	%
Smart Car	--	--	25,496	1.88	39,747	2.04	54,290	2.33
PHEV	--	--	30,867	2.28	42,829	2.20	57,137	2.45
HEV	--	--	85,367	6.31	134,098	6.89	175,356	7.51
Van	101,830	12.70	115,874	8.56	165,759	8.51	195,708	8.38
SUV	85,650	10.68	155,999	11.52	221,006	11.35	276,504	11.84
CUV	94,140	7.46	153,054	11.30	202,333	10.39	236,855	10.15
Pickup truck	67,290	13.29	167,921	12.40	244,067	12.53	307,010	13.15
Midsize car	99,470	12.41	118,221	8.73	164,048	8.42	185,536	7.95
Large car	96,800	11.25	131,334	9.70	191,106	9.81	224,706	9.62
Luxury car	90,210	12.07	118,762	8.77	173,914	8.93	167,889	7.19
Compact car	59,830	8.39	84,875	6.27	125,157	6.43	157,159	6.73
Subcompact car	106,520	11.74	166,118	12.27	243,175	12.49	296,519	12.70
Average vehicle ownership	1.94		2.16		2.25		2.31	

Under the **FEEBATE policy**, household auto ownership levels are predicted to rise, more so than in any other scenario, thanks to the effective reduction in efficient-vehicle prices. As expected, there is a preference for more fuel efficient vehicles under this scenario (relative to TREND), resulting in roughly a 19% market share for HEVs and PHEVs by 2034. Nevertheless, purchases of less efficient vehicles remain solid and the strategy's revenues are estimated to exceed payouts by 12%, 33% and 37% in years 2014, 2024 and 2034. At the same time, total receipts are estimated to be rising (at a somewhat decreasing rate) over time (at roughly 3.4% a year). Under the FEEBATE scenario, the market share of compact cars and subcompact cars is predicted to rise, every year, while shares of SUVs, CUVs and pickup trucks fall. Results from the FEEBATE scenario suggest that an increasing share of the two-vehicle and three-vehicle households will hold at least one HEV and PHEV in their vehicle fleet, while HEV and PHEV shares may fall very slightly across four-vehicle households. The FEEBATE scenario yielded the highest total share of HEVs and PHEVs, as compared to the other scenarios modeled.

Table 4.3: Fleet Composition under Feebate Scenario (FEEBATE)

	Year 2015		**Year 2025**		**Year 2034**	
	Count	%	Count	%	Count	%
Smart Car	30,792	2.28	46,534	2.43	64,304	2.69
PHEV	56,823	4.22	81,613	4.27	112,185	4.69
HEV	167,555	12.43	263,875	13.80	345,409	14.43
Van	115,537	8.57	162,230	8.48	198,613	8.30
SUV	141,122	10.47	186,442	9.75	237,212	9.91
CUV	135,879	10.08	175,666	9.18	205,292	8.58
Pickup truck	117,682	8.73	165,786	8.67	207,699	8.68
Midsize car	117,901	8.75	161,796	8.46	187,386	7.83
Large car	117,673	8.73	169,821	8.88	203,782	8.51
Luxury car	105,839	7.85	149,183	7.80	188,399	7.87
Compact car	81,629	6.06	118,854	6.21	153,787	6.42
Subcompact car	159,188	11.81	230,823	12.07	289,597	12.10
Average vehicle ownership	2.15		2.21		2.37	

The third scenario modeled assumed the cost of gas to be $5 per gallon. In this scenario, the gas price affected vehicle disposal decisions but not vehicle purchase decisions [due to statistically insignificant purchase-model regression results]. The $5-per-gallon **(PRICING) scenario** was estimated to have only a minor impact on the composition of vehicles owned, with slight reductions in the share of Smart Cars, PHEVs and vans, alongside higher shares of compact and subcompact cars (20%), SUVs/CUVs and HEVs. More specifically, 5% to 20% of the two-vehicle households (with the share rising over time) chose to acquire a HEV in each of the model years, under this scenario. Decreasing shares of PHEV presence are simulated over time, in four-vehicle households, falling from roughly 3.1% to 2.5%.

Table 4.4: Fleet Composition under Gas Tax Scenario (PRICING)

	Year 2015		**Year 2025**		**Year 2034**	
	Count	%	Count	%	Count	%
Smart Car	26,259	1.94	39,559	2.02	55,692	2.38
PHEV	29,409	2.17	43,278	2.21	55,799	2.38
HEV	86,565	6.39	132,618	6.78	180,728	7.71
Van	88,827	6.56	128,519	6.57	155,943	6.65
SUV	197,840	14.61	281,490	14.39	338,833	14.45
CUV	153,163	11.31	205,462	10.50	233,865	9.97
Pickup truck	150,268	11.10	218,905	11.19	279,826	11.93
Midsize car	123,314	9.11	172,287	8.81	194,694	8.30
Large car	125,074	9.24	183,051	9.36	219,211	9.35
Luxury car	121,430	8.97	179,360	9.17	169,336	7.22
Compact car	69,889	5.16	102,421	5.24	131,872	5.62
Subcompact car	181,851	13.43	268,945	13.75	329,022	14.03
Average vehicle ownership	2.16		2.26		2.32	

The final scenario, which modeled the impact of a $4,100 reduction to the base price of PHEVs, simulated the PHEV's market share to rise to 6.14% by 2034. Three-vehicle households are estimated to be the highest adopters of HEVs (with 17.1% of such households predicted to own at least one HEV by 2034), and two-vehicle households are simulated to be the highest adopters of PHEVs (at 16.7% of such household), as shown in Table 4.6. These results complement the work of Gallagher and Muehlegger (2008), who estimated that 6%, 27% and 36% of current U.S.

HEV sales can be attributed to tax incentives, rising gasoline prices, and social preferences, respectively.

Table 4.5: Fleet Composition under Optimistic PHEV Pricing Scenario (LOWPRICE)

	Year 2015		**Year 2025**		**Year 2034**	
	Count	%	Count	%	Count	%
Smart Car	23,047	1.72	34,044	1.78	48,099	2.03
PHEV	75,422	5.62	110,436	5.77	145,847	6.14
HEV	74,037	5.52	114,963	6.01	152,161	6.41
Van	114,801	8.56	162,813	8.51	193,280	8.14
SUV	148,937	11.10	206,073	10.77	260,235	10.96
CUV	147,020	10.96	193,261	10.10	225,886	9.51
Pickup truck	157,142	11.72	227,748	11.91	288,051	12.13
Midsize car	117,127	8.73	161,132	8.42	183,235	7.72
Large car	127,392	9.50	184,248	9.63	225,886	9.51
Luxury car	114,936	8.57	167,362	8.75	218,013	9.18
Compact car	81,781	6.10	118,712	6.21	150,287	6.33
Subcompact car	159,711	11.91	231,832	12.12	283,715	11.95
Average vehicle ownership	2.14		2.21		2.29	

Table 4.6: HEV and PHEV Vehicle Adopters under Optimistic PHEV Pricing Scenario (LOWPRICE)

HEV Adopters			
Year	2-vehicle households	3-vehicle households	4-vehicle households
2015	15.00%	15.90%	13.00%
2025	16.10%	16.50%	13.90%
2034	16.70%	17.10%	15.10%
PHEV Adopters			
Year	2-vehicle households	3-vehicle households	4-vehicle households
2015	15.30%	13.70%	9.20%
2025	15.50%	13.00%	7.90%
2034	16.70%	12.90%	7.40%

4.4 VEHICLE USAGE

The vehicle usage model developed in Section 3.6.6 is applied annually to every record. This section describes the results of the vehicle usage model. In order to appreciate the changes in emissions due to changing vehicle ownership patterns and new vehicle technologies available for purchase, a vehicle usage model using NHTS 2001 data was built. For example, utility factor curves coupled with expected vehicle usage levels give an insight into the gasoline and electricity consumption for PHEVs [Markel and Simpson (2006), Gonder et al. (2009), Simpson (2006) and Kromer and Heywood (2007)]. Also, differentiating vehicle miles traveled for each vehicle in a household allows one to map the fuel consumption patterns at a disaggregate level. Figure 4.4 shows VMT for each of the vehicle classes across the four scenarios. Consistent with vehicle ownership shares, the pricing scenario has the largest fraction of VMT in the small cars vehicle class (this is due to the high share of compact and subcompact cars). Table 4.7 shows total scenario VMT along with the base year VMT. The base case had 1,016,541 vehicles generating about 8,377 million vehicle miles. Table 4.6 provides predictions for the year 2034.

In the TREND case, total household VMT is expected to increase by 153% over 25 years. The highest increase is in the case of FEEBATE scenario (164%). Implementing the feebate policy is simulated to increase the average VMT per vehicle per year, to 9222. These results are in line with the work of Greening et al. (2000), which states that technology improvements could result in an increase in supply of energy services. This is also known as the rebound effect.

Table 4.7: Simulated Household Vehicle Miles Traveled in 2034

	Trend Scenario (TREND)	**Feebates (FEEBATE)**	**Gas at $5/gallon (Pricing)**	**Optimistic PHEV Incremental Pricing (LOWPRICE)**
2009				
Total (million miles)	8,377			
2034				
Total (million miles)	21,155	22,091	17,594	21,758
% Change from TREND		4.43	-16.83	2.85
Average VMT	9,061	9,222	7,503	9,279

The greatest variation in vehicle usage levels, by vehicle class, is observed in HEVs across scenarios (as shown in Figure 4.4). Thanks to the high percentage of SUVs and CUVs among vehicles owned in the TREND scenario, these vehicle classes' usage levels are higher than those of other vehicle classes in the TREND scenario. The usage of compact and subcompact cars increases under the pricing scenario (36% of total VMT), while relatively steady usage levels are noticeable with Smart and midsized cars (across scenarios). PHEVs enjoy their highest share of total VMT in the LOWPRICE scenario, as compared to the other scenarios. Due to a higher count of HEVs in the FEEBATE scenario, such vehicles enjoy the highest VMT levels in that scenario, HEVs are used more than PHEVs in all scenarios, but nearly the same in the LOWPRICE scenario. Overall, thanks to the sign and magnitude of the fuel cost parameter in the vehicle usage model, the region's overall VMT fell by 17% in the PRICING scenario as compared to the trend scenario (in year 2034). And this is associated with an estimated 21% reduction in fuel consumption under that scenario, relative to TREND. Interestingly, this is quite consistent with the elasticity estimates of Small and van Dender (2007), given the doubling in gas price modeled here.

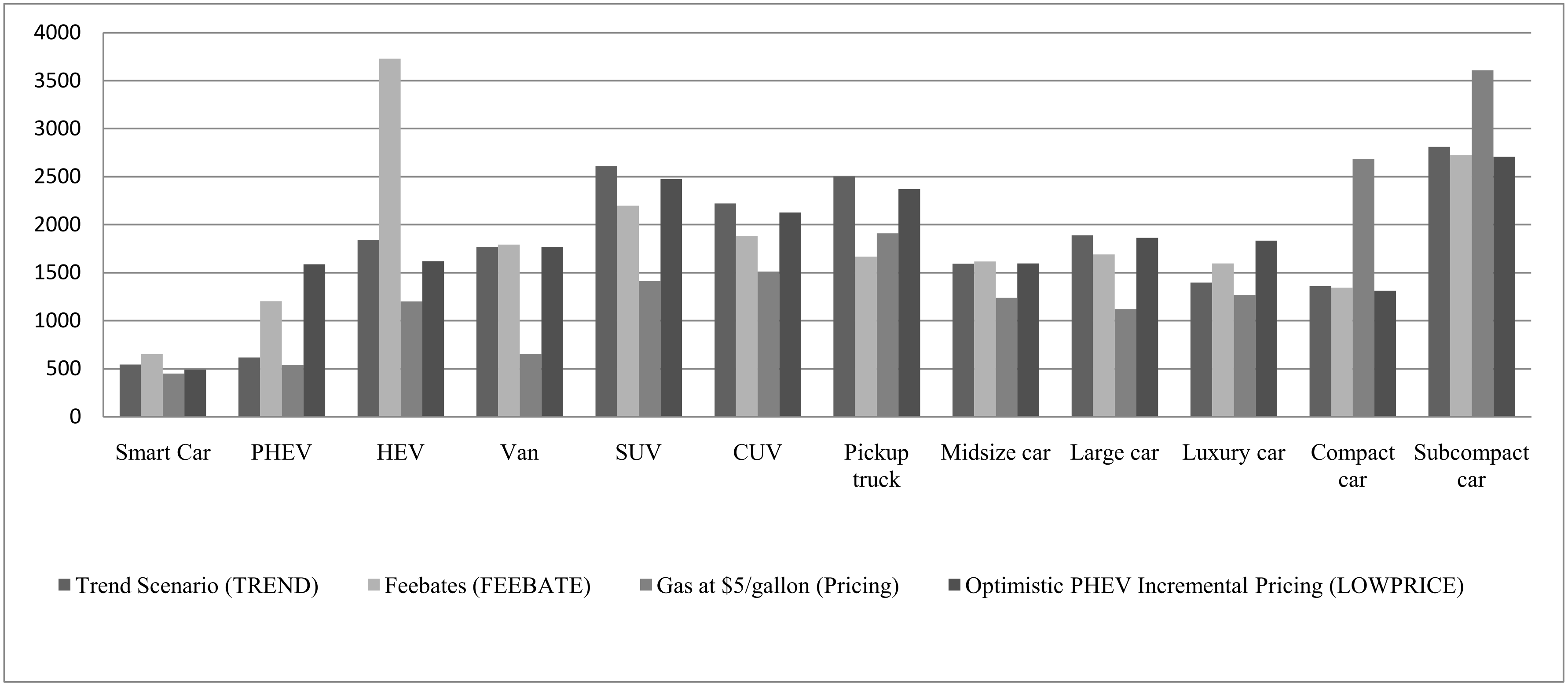


Figure 4.4: Simulation Household VMT by Class in 2034

4.5 EMISSIONS FROM VEHICLE FUEL CONSUMPTION

To translate VMT changes into GHG emissions, EPA's (2007) standard conversion values are used, recognizing lifecycle emissions (accounting for energy and emissions from upstream production and transport process). According to EPA (2007), a gallon of gasoline is likely to be responsible for 11.52 kilograms (or 25.4 pounds) of carbon dioxide (CO_2). Of course, automobiles also emit methane (CH_4) and nitrous oxide (N_2O) from their tailpipes, as well as hydrofluorocarbons (HFC) from leaking air conditioners (EPA, 2005). CH_4, N_20 and HFC emissions represent 5% to 6% of the passenger vehicle GHG emissions, while CO_2 emissions account for the other 94% to 95% (EPA, 2005). However, these other GHGs are not considered here. Instead, we focus on emissions from power plants for the PHEVs in the mix of future vehicles.

In this thesis, VMT per vehicle and vehicle emissions are estimated using the EPA- rated average fuel economy of each vehicle class (rather than simulating speeds as well, which can affect fuel economy). Table 4.8 provides the results. For estimating the GHG emissions of the Prius PHEV's electric power trains, we first compute the percentage of electric miles, using the utility factor curves discussed in Section 2.3.1. Using EIA (2000) estimates of emissions from electricity generation, we then calculated the total emissions. Table 4.8 provides these summarized results.

Table 4.8: Greenhouse Gases & Related Emissions Estimates from Household Vehicles in 2034

	Trend Scenario (TREND)	Feebates (FEEBATE)	Gas at $5/gallon (PRICING)	Optimistic PHEV Incremental Pricing (LOWPRICE)
2009				
CH_4, N_2O and HFC	453			
CO2e	9,055			
2034				
CH_4, N_2O and HFC	1,380	1,321	1,092	1,376
CO2e	26,346	25,353	20,545	26,467
% Change of CO2e from TREND		-3.77	-22.02	0.29
% Change of CH_4, N_2O and HFC from TREND		-4.28	-20.87	0.46

4.6 DISCUSSION

The objective of this thesis was to estimate household vehicle fleet evolution and related greenhouse gas emissions from the personal transportation sector in Austin, Texas over a period of 25 years. Vehicle fleet evolution patterns and GHG emissions were estimated under various scenarios. Of course, no scenario is perfectly realistic (since gas prices will likely be changing under all scenarios, along with Corporate Average Fuel Economy targets, vehicle prices, and so forth), but in the scenarios modeled here do appear to give readers an important sense of potential variations in future fleet makeups and emissions savings. Ownership shares of PHEVs, HEVs and Smart Cars are of great interest to manufacturers and policymakers, and these shares are relatively variable across scenarios due to their lower starting counts. In the TREND scenario, the microsimulation framework is integrated with a vehicle usage model and estimates are provided without any other policy changes. This is the base scenario against which all other policy scenario results are evaluated.

The FEEBATE scenario's results are also quite interesting: while its vehicle ownership and use levels are predicted to be comparatively higher, across all scenarios, its GHG emission levels are expected to be slightly lower than the TREND, PRICING and LOWPRICE scenarios. It is expected to generate net revenues of $971 per new vehicle sold and also facilitate mobility while reducing overall CO2 emissions (though only slightly, by 3.77% of light-vehicle fleet emissions, relative to trend results).

In the PRICING scenario, gas prices were set to $5 per gallon (rather than the trend scenario's $2.5/gallon). Vehicle usage levels dropped by 17% due to the responsive fuel cost parameter in the

VMT model. CO_2 emissions fell by 22% due to the combined effect of lower vehicle use and shifted ownership shares. Under this scenario, 20% of the light-duty/personal fleet is predicted to be small cars (compact and subcompact cars) by 2034 (as opposed to the 14% share in the 2006/2007 Austin Travel Survey).

In the LOWPRICE scenario, PHEV ownership increases across households over time (Table 4.5). Vehicle usage levels in this scenario are about 3% more than the TREND case. And GHG emissions are similar to the TREND scenario.

4.7 SUMMARY

This chapter presented the results of the 25-year simulated evolution of Austin's vehicle fleet as well as fuel consumption patterns and emission levels under different scenarios. It was observed that auto ownership increases gradually and electric powertrains can reduce overall GHG emissions if steps are taken in the right direction to encourage people to purchase fuel efficient vehicles. The next chapter provides a thesis summary and recommendations for future work.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

The study of vehicle ownership and use patterns is fundamental to the understanding of transportation behavior. This thesis utilized a microsimulation framework for anticipating the future vehicle fleet, adoption of PHEVs and estimating future greenhouse gas emissions. A vehicle choice survey was conducted which sought to appreciate vehicle ownership patterns and attitudes toward potential policies and vehicle technologies. With the help of a variety of revealed, stated preference questions, vehicle choice and travel behavior models, the thesis estimates future household vehicle fleet composition and fuel consumption patterns, and compares them across four distinct policies over a 25-year horizon in Austin, Texas. This work also provides recommendations to reduce GHG emissions and make the future fleet more fuel efficient.

As expected, PHEV adoption is the highest (6.14%) in the reduced PHEV (LOWPRICE) scenario, and HEVs' share is highest (14.43%) in the FEEBATE case. In the gas price rise (PRICING) scenario, small cars enjoy their largest share of the personal vehicle fleet (at 20%), just above their share in the TREND scenario (19%), LOWPRICE scenario (18%) and FEEBATE scenario (18%). Midsize cars have lower shares across all scenarios (relative to TREND), which may be due to the availability of HEVs and PHEVs, which have similar drivability characteristics. Average vehicle ownership per household is simulated to increase by 19 percent in the TREND scenario, though household sizes are expected to fall slightly (by 3.3%) over the simulation period. The highest average vehicle ownership is simulated under the FEEBATE scenario, with an estimated increase in average vehicle ownership of 22%. This may be due to overall lower vehicle fleet age affecting the transaction decision. In comparison with the other scenarios, simulated vehicle ownership falls when gas prices double (to $5 per gallon). In comparison to the base year (2009) total VMT, year 2034 VMT levels are predicted to increase 154%, 165%, 111% and 161% by year 2034 in the TREND, FEEBATE, PRICING and LOWPRICE scenarios, respectively, as population rises 70%. While a feebate policy is estimated to increase the market share of electric vehicles to a maximum of 20%, gas pricing appears to be the most effective scenario for curbing GHG emissions. The PRICING scenario reduces the CO2e emissions by 22%, and CH_4, N_2O and HFC by 21%, relative to TREND (in year 2034).

As vehicle ownership and usage levels are expected to rise over time, along with population and household costs, it becomes critical that policymakers and others appreciate the steps needed to meaningfully curb GHG emissions to hit policy targets. As noted in Chapter 4, a recent IEA (2008) report anticipates only single-digit shares for HEVs (and PHEVs – together) through 2015, due to a lack of public awareness, reluctance by vehicle manufacturers and conflicting interests.

A 2009 IEA report proposes a range of polices to promote the sales of BEV, HEVs and PHEVs. For example, consumer willingness to pay for electric vehicles (BEVs, HEVs and PHEVs) might rise if government-industry partnerships can support consumer education programs in this area, and if manufacturers can more accurately report operating information on range as well as recharging times. Such policies can increase customer confidence, and be coupled with policies to support research and development by vehicle manufacturers, feebate policies, battery leasing opportunities, road tolling, provision of recharging infrastructure, and so forth. Of course, predicting the future of vehicle holdings and use is a complex endeavor. The following section provides some recommendations for model enhancements.

5.1 RECOMMENDATIONS

Since microsimulation involves simulating the agent behavior in the system, the data sets that represent the system and the models used to simulate the behavior of the agents must be robust. More simulations on the heels of faster run times would be useful to getting a better sense of model performance and more scenarios' likely impacts.

Dynamic and more detailed models of vehicle ownership and use also would be useful, to recognize past and present vehicles owned (and brand loyalty, for example) and their usage, along with any effects of gas prices on vehicle ownership levels (not just vehicle types). Simultaneous equations models, for purchase and use, may also give better results. Inclusion of a more sophisticated vehicle retirement model and the tracking of vehicle exchanges across households (and other regions) over the simulation period could enhance forecasting abilities as well.

There are several areas that remain open for further exploration. More realistic scenarios, with more diverse vehicle options, in tandem with careful in-person interviews can help ensure more realistic responses on stated preference questions, particularly for vehicles that do not yet exist. Recognition of vehicle use patterns (vis-à-vis the vehicle choice decision) along with unexpected vehicle loss (due to crashes and theft, for example) would enhance the information content and reliability of results. Greater reliance on past /revealed transactions data would also be useful. Finally, information about driving habits, travel behavior, frequency and length of long-distance trips affect the use, fuel economy and emissions from household vehicle fleets, and may be critical to PHEV adoption feasibility, greenhouse gas impacts, and other attributes of great interest to local and global communities. New survey instruments and first-hand data collection may remain core to addressing such questions.

In summary, vehicle fleet evolution patterns and greenhouse gas emissions from Austin's personal vehicle fleet were estimated here, under various scenarios, and the forecasts illuminate several trends and policy possibilities. For example, labeling and advertising fuel expenditures rather than fuel economy appears likely to help vehicle purchasers make much more informed decisions. Gas pricing or taxation appears to offer far more greenhouse gas savings than either a feebate or reduced-PHEV pricing scenario, and larger data sets, from households across the U.S., should prove helpful in illuminating such policy questions for the nation as a whole. Land use patterns may also be key for the number and type of vehicles owned, thus impacting overall miles traveled by automobile. But trends under all tested scenarios seem highly inadequate in view of likely emissions targets. Far more than a doubling of gas prices appears needed.

REFERENCES

Axsen, J., and K. Kurani. 2008. The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-22. Accessed from http://pubs.its.ucdavis.edu/publication_detail.php?id=1191 on April 12, 2009.

Berkovec, J. 1985. Forecasting Automobile Demand Using Disaggregate Choice Models. *Transportation Research B,* 19(4): 315-329.

Berkovec, J., and J. Rust. 1985. A Nested Logit Model of Automobile Holdings for One Vehicle Households. *Transportation Research B,* 19(4): 275-285.

Bhat, C.R. and S. Sen. 2006. Household Vehicle Type Holdings and Usage: An Application of the Multiple Discrete-Continuous Extreme Value (MDCEV) Model, *Transportation Research B*, 40 (1): 35-53.

Bhat, C.R., S. Sen, and N. Eluru. 2008. The Impact of Demographics, Built Environment Attributes, Vehicle Characteristics, and Gasoline Prices on Household Vehicle Holdings and Use. *Transportation Research Part B*, 43(1): 1-18.

Bina, M., D. Suescun, and K. Kockelman. 2006. Location Choice vis-à-vis Transportation: The Case of Recent Home Buyers. Proceedings of the 85th Annual Meeting of the Transportation Research Board, Washington, D.C.

Burnham, A., M. Wang and Y. Wu. 2006. Development and Applications of GREET 2.7 The Transportation Vehicle-Cycle Model, ANL/ESD/06-5, Energy Systems Division, Argonne National Laboratory.

Burnham, A. 2007. Introduction of the GREET 2.7 Model, Center for Transportation Research, Argonne National Laboratory.

British Broadcasting Corporation BBC (2002) The U.S. and Climate Change. Accessed from http://news.bbc.co.uk/2/hi/americas/1820523.stm on September 30, 2008.

Brownstone, D. and T. Golob. 2009. The Impact of Residential Density on Vehicle Usage and Energy Consumption. *Journal of Urban Economics*, 65: 91-98.

CalCars. 2003. The California Cars Initiative 2003. Plug-In Hybrids, Palo Alto, California. Available at http://www.calcars.org/.

Caliper Corporation. 2002. TransCAD Transportation GIS Software, Caliper Corporation, America.

Choo, S., and P. Mokhtarian. 2004. What Type of Vehicle do People Drive? The Role of Attitude and Lifestyle in Influencing Vehicle Type Choice. *Transportation Research A*, 38 (3): 201-222.

Creedy, J., G. Kalb and H. Kew. 2005. Confidence Intervals for Policy Reforms in Behavioral Tax Microsimulation Modeling. Working Paper.# 936. Accessed from http://ideas.repec.org/p/mlb/wpaper/936.html on October 20, 2009.

Department of Health and Human Services. 1997. TRIM3 (Transfer Income Model, Version 3). Accessed from http://trim3.urban.org/ on November 27, 2009.

Dubin, J. and D. McFadden. 1984. An Econometric Analysis of Residential Appliance Holdings and Consumption. *Econometrica*, 52 (2): 345-362.

Electric Power Research Institute (EPRI). 2001. Comparing the Benefits and Impacts of Hybrid Vehicle Options. Report# 1000349. Available at http://mydocs.epri.com/docs/public/000000000001000349.pdf.

Elgowainy, A. 2007. Introduction to GREET 1.7 Graphical User Interface, Center for Transportation Research, Argonne National Laboratory, June 25-26.

Eluru, N., A. Pinjari, J. Guo, I. Sener, S. Srinivasan, R. Copperman and C. Bhat. 2008. Population Updating System Structures and Models Embedded Within the Comprehensive Econometric Microsimulator for Urban Systems (CEMUS). Proceedings of the Transportation Research Board's 87th Annual Meeting, Washington, DC.

Environmental Protection Agency (EPA). 1994. Automobile Emissions: An Overview. Accessed from http://www.epa.gov/oms/consumer/05-autos.pdf on October 20, 2009.

Environmental Protection Agency (EPA). 1999. Reformulated Gasoline Emission Facts. Report #: DOE/EIA-420. Accessed from http://www.epa.gov/OMS/f99040.htm on October 25, 2009.

Energy Information Agency (EIA). 2002. Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000. Report No. DOE/EIA-0348 http://www.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf. Accessed June 20, 2009.

Environmental Protection Agency (EPA). 2005. Emission Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle. Report #: EPA420. Accessed from http://www.epa.gov/OMS/climate/420f05004.htm on December 21, 2008.

Energy Information Administration (EIA). 2007. Renewable Fuel Standard Program, Chapter 6 Lifecycle Impacts on Fossil Energy and Greenhouse Gases. Accessed from http://www.epa.gov/otaq/renewablefuels/420r07004chap6.pdf. on November 5, 2009.

Environmental Protection Agency (EPA). 2007. Greenhouse Gas Emissions. Accessed from http://www.epa.gov/climatechange/emissions/index.html on December 21, 2008.

Environmental Protection Agency (EPA). 2008. Clean Air Act. Accessed from http://www.epa.gov/air/caa on October 25, 2009.

Energy Information Administration (EIA). 2009. U.S. Product Supplied of Reformulated Motor Gasoline. http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MGRUPUS1&f=M. Accessed July 20, 2009.

Environmental Protection Agency (EPA). 2009. Country Analysis Briefs. Accessed from http://www.eia.doe.gov/emeu/cabs/China/pdf.pdf on October 20, 2009.

Espey, M., and S. Nair. 2005. Automobile Fuel Economy: What is it Worth?. *Contemporary Economic Policy*, 23 (3): 317-323.

Fang, H. 2008. A Discrete-Continuous Model of Households' Vehicle Choice and Usage, with an Application to the Effects of Residential Density. *Transportation Research B*, 42(9): 736-758.

Feng, Y., D. Fullerton, and L. Gan. 2005. Vehicle Choices, Miles Driven and Pollution Policies. Working paper 11553, National Bureau of Economic Research. Accessed from http://works.bepress.com/cgi/viewcontent.cgi?article=1008&context=don_fullerton on December 25, 2008.

First Electric Cooperative. 2009. PHEV FAQ 2009. http://www.firstelectric.coop/content.cfm?id=2107. Accessed on April 21, 2009.

Gallagher, K., and E. Muehlegger. 2008. Giving Green to Get Green? The Effect of Incentives and Ideology on Hybrid Vehicle Adoption. Working Paper. Available at http://ksghome.harvard.edu/~emuehle/Research%20WP/Gallagher%20and%20Muehlegger%20Feb_08.pdf.

Giffin, B. and L. Miller. 2009. The Changing U.S. Auto Industry-Consumer Sentiment During Challenging Times. Accessed from http://www.polk.com/TL/MS_200903_ConsumerSentiment.pdf on Dec 3, 2009.

Goebel, D. 2009. The Changing U.S. Auto Industry- The Impact of Declining New Vehicle Sales on the Aftermarket Business. Accessed from http://www.polk.com/TL/MS_200903_ChangingAutoIndustry_Aftermarket.pdf on Dec 3, 2009.

Gonder, J., A. Brooker, R. Carlson and J. Smart. 2009. Deriving In-Use PHEV Fuel Economy Predictions from Standardized Test Cycle Results. Report No. NREL/CP-540-46251. http://www.nrel.gov/vehiclesandfuels/vsa/pdfs/46251.pdf. Accessed May 16, 2009.

Goulias, K.G., and R. Kitamura. 1992. Microsimulation for Travel Demand Forecasting: A Dynamic Model System of Household Demographics and Mobility. Institute of Transportation Studies Research Report, UCD-ITS-RR-92-4, University of California, Davis.

Greening, L., D. L. Greene and C. Difiglio. 2000. Energy Efficiency and Consumption-The Rebound Effect - A Survey. *Energy Policy*, 28: 389-401.

Greene, D. L., P. Patterson, M. Singh and J. Li. 2005. Feebates, Rebates and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy. *Energy Policy*, 33: 757-775.

Greene, D. 2009. Uncertainty, Loss Aversion and Markets for Energy Efficiency. Presented at the presented at the Workshop on the Economics of Technologies to Combat Global Climate Change. Available at http://www.iiasa.ac.at/Research/TNT/WEB/Workshops/tech09/Greene_tech_snowmass.pdf.

Greene, D. L., J. German and M. A. Delucchi. 2009. Fuel Economy: The Case for Market Failure. Chapter 11 in D. Sperling and J. Cannon, *Reducing Climate Impacts in the Transportation Sector.*

Gregor, B. 2009. GreenSTEP: Greenhouse Gas State Transportation Emissions Planning Model. Proceedings of 50th Annual Transportation Research Forum.

Guo, J. and C. R. Bhat. 2007. Population Synthesis for Microsimulating Travel Behavior. *Transportation Research Record*, 2014: 92-101.

Hao, J., J. Hu and L. Fu. 2006. Controlling Vehicular Emissions in Beijing during the Last Decade. *Transportation Research A*, 40: 639-651.

Internet World Stats.2007. United States of America: Internet Usage and Broadband Usage Report. Accessed from
http://www.internetworldstats.com/am/us.htm. Accessed June 27, 2009.

International Energy Agency (IEA). 2008. Outlook for Hybrid and Electric Vehicles. Accessed from http://www.ieahev.org/pdfs/ia-hev_outlook_2008.pdf on September 17, 2009.

International Energy Agency (IEA). 2009. Technology Roadmap: Electric and Plug-In Hybrid Electric Vehicles. Accessed from http://www.iea.org/papers/2009/EV_PHEV_Roadmap.pdf on November 4, 2009.

Kitamura, R., E. Pas, C. Lula, T. Lawton and P. Benson. 1996. The Sequenced Activity Mobility Simulator (SAMS): An Integrated Approach to Modeling Transportation, Land Use and Air Quality. *Transportation*, 23: 267-291.

Kitamura, R., T. F. Golob, T. Yamamoto and G. Wu. 2000. Accessibility and Auto Use in a Motorized Metropolis. Proceedings at the 79th Transportation Research Board Annual Meeting, Washington, DC.

Kockelman, K.M. and Y. Zhao. 2000. Behavioral Distinctions: The Use of Light-Duty Trucks and Passenger Cars. *Journal of Transportation and Statistics,* 3(3): 47-60.

Kromer, M.A. and J.B. Heywood. 2007. Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet, MIT Laboratory for Energy and the Environment, Cambridge, Massachusetts. Accessed from http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/kromer_electric_powertrains.pdf on March 25, 2009.

Kumar, S. 2007. Microsimulation of Household and Firm Behaviors: Coupled Models of Land Use and Travel Demand in Austin, Texas. Master's Thesis. Department of Civil Engineering, The University of Texas at Austin.

Kurani, K., and T. Turrentine. 2004. Automobile Buyer Decisions about Fuel Economy and Fuel Efficiency. Final Report to United States Department of Energy and Energy Foundation.

Kurani, K., R. Heffner and T. Turrentine. 2009. Driving Plug-In Hybrid Electric Vehicles: Reports from U.S. Drivers of HEVs converted to PHEVs. Proceedings at the 88th Transportation Research Board Annual Meeting, Washington, DC.

Langer, A., N. Miller. (2008). Automobile Prices, Gasoline Prices, and Consumer Demand for Fuel Economy. Economic Analysis Group Discussion Paper, University of California, Berkeley. Accessed from http://drwww.wm.edu/as/economics/research/seminars/seminardocs/Miller_Langer.pdf on September 28, 2009.

Larrick, R.P. and J.B. Soll. 2008. The MPG Illusion. *Science*, 320: 1593-1594.

Lave, C. A., and K. Train. 1979. A Disaggregate Model of Auto-Type Choice. *Transportation Research A,* 13(1): 1-9.

Lemp, J., and K. Kockelman. 2008. Quantifying the External Costs of Vehicle Use: Evidence from America's Top Selling Light-Duty Models. *Transportation Research D,* 13: 491-504.

Mannering, F., and C. Winston. 1985. A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization. *Rand Journal of Economics,* 16(2): 215-236.

Mannering, F., C. Winston, and W. Starkey. 2002. An Exploratory Analysis of Automobile Leasing by US Households. *Journal of Urban Economics,* 52(1): 154–176.

Manski, C. F., and L. Sherman. 1980. An Empirical Analysis of Household Choice among Motor Vehicles. *Transportation Research A,* 14(5/6): 349-366.

Markel, T., and A. Simpson. 2006. Plug-In Hybrid Electric Vehicle Energy Storage System Design. Report No. NREL/CP-540-39614 http://www.nrel.gov/vehiclesandfuels/vsa/pdfs/39614.pdf. Accessed May 16, 2009.

Markel, T. 2006a. Plug-In HEV Vehicle Design Options and Expectations. Report No. NREL/PR-40630 http://www.nrel.gov/docs/fy06osti/40630.pdf. Accessed April 14, 2009.

Markel, T. 2006b. Plug-In HEV: Current Status, Long-Term Prospects and Key Challenges Report No. NREL/PR-40239 http://www.nrel.gov/docs/fy06osti/40239.pdf. Accessed April 14, 2009.

McWethy, L.M. 2006. Comparing Microscopic Activity-Based and Traditional Models of Travel Demand: An Austin Area Case Study. Master's Thesis. Department of Civil Engineering, The University of Texas at Austin.

Mohammadian, A., and E. J. Miller, 2003a. An Empirical Investigation of Household Vehicle Type Choice Decisions. *Transportation Research Record*, 1854: 99-106.

Mohammadian, A., and E. J. Miller, 2003b. Dynamic Modeling of Household Automobile Transactions. *Transportation Research Record*, 1831: 98-105.

Musti, S., K. Kortum and K. Kockelman. 2009. Household Energy Use and Travel: Opportunities for Behavioral Change. Presented at the 12th TRB National Transportation Planning Applications Conference, in Houston. Accessed from http://www.caee.utexas.edu/prof/kockelman/public_html/TRB10EnergySurvey.pdf on June 30, 2009.

National Household Travel Survey (NHTS). 2001. National Data on the Travel Behavior of American Public. Accessed from http://nhts.ornl.gov/download.shtml on August 22, 2009.

National Research Council (NRC). 2006. State and Federal Standards for Mobile Source Emissions. Available at http://www.nap.edu/catalog/11586.html.

Nye, R., D. Greene, J. Hopson and J. Saulsbury. 2003. Providing Consumers with Web-Based Information on the Environmental Effects of Automobiles. Report # ORNL/TM-2003/166. http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2003_166.pdf. Accessed June 25, 2009.

Planung TransportVerkehr AG (PTV). 1992. VISSIM. Accessed from http://www.ptvamerica.com/ on October 20, 2009.

Puller, S.L., and L.A. Greening. 1999. Household Adjustment to Gasoline Price Change: An Analysis Using 9 Years of US Survey Data. Energy Economics, 21(1): 37-52.

Prillwitz, J., S. Harms, and M. Lanzendorf. 2006. Impact of Life Course Events on Car Ownership. Poster for the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., January 22-26, 2006.

Rohaly, J., A. Carasso and M. Saleem. 2005. The Urban-Brookings Tax Policy Center Microsimulation Model: Documentation and Methodology for Version 0304. Accessed from http://www.taxpolicycenter.org/publications/url.cfm?ID=411136 on October 20, 2009.

Rousseau, A. 2007. Designing Advanced Vehicle Powertrains Using PSAT, Greet Training, Center for Transportation Research, Argonne National Laboratory, June 25.

Roy, R. 1947. La Distribution du Revenu Entre Les Divers Biens. *Econometrica*, 15: 205-225.

Santini, D. 2006. Fuel Consumption, Operational Attributes and Potential Markets for Plug-in Hybrid Technologies. Available at http://www.transportation.anl.gov/pdfs/HV/388.pdf.

Shidore, N., T. Bohn, M. Duoba, H. Lohse-Busch, and P. Sharer. 2006. Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology. Available at http://www.transportation.anl.gov/pdfs/HV/463.pdf.

Simpson, A. 2006. Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology. Report No. NREL/CP-540-40485. http://www.nrel.gov/vehiclesandfuels/vsa/pdfs/40485.pdf. Accessed April 14, 2009.

Small, K. A., and C. Kazimi. 1995. On the Costs of Air Pollution from Motor Vehicles. *Journal of Transport Economics and Policy*, 29(1): 7-32.

Small, K. A., and K. Van Dender. 2005. The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using U.S. State Data, 1966-2001. University of California Energy Institute's (UCEI) Energy Policy and Economics Working Paper Series. Accessed from http://www.ucei.berkeley.edu/PDF/EPE_014.pdf on November 20th, 2009.

Small, K. A., and K. Van Dender. 2007. Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *Energy Journal*, 28(1): 25-51.

Smith, C., G. Spitz, M. Fowler and T. Seely. 2009a. Internet Access: Is Everyone Online Yet and Can We Survey Them There? Presented at the 12th TRB National Transportation Planning Applications Conference, in Houston, Texas.

Smith, C., M. Fowler, E. Greene and C. Nielson. 2009b. Carbon Emissions and Climate Change: A Study of Attitudes and their Relationship with Travel Behavior. Presented at the 12th TRB National Transportation Planning Applications Conference, in Houston, Texas.

Sperling, D., and N. Lutsey. 2009. Energy Efficiency in Passenger Transportation. *The Bridge*, 39(2):22-30.

Subramanyam, K., U. Diwekar, Y. Wu and M. Wang. 2008. New stochastic simulation capability applied to the GREET model. *The International Journal of Life Cycle Assesment*, 13(3): 278-285.

Tirumalachetty, S., K. Kockelman, and S. Kumar. 2009. Micro-Simulation Models of Urban Regions: Anticipating Greenhouse Gas Emissions from Transport and Housing in Austin, Texas. Presented for the 88th Annual Meeting of the Transportation Research Board, Washington, D.C.

Tirumalachetty, S. 2009. Microsimulation of Household and Firm Behaviors: Anticipation of Greenhouse Gas Emissions for Austin, Texas. Master's Thesis. Department of Civil Engineering, The University of Texas at Austin.

Train, K. 1980. A Structured Logit Model of Auto Ownership and Mode Choice. *Review of Economic Studies*, 47: 357-370.

Train, K., W. Davis and M. Levine. 1996. Fees and Rebates on New Vehicles: Impacts on Fuel Efficiency, Carbon dioxide Emissions and Consumer Surplus. *Transportation Research* E, 33(1): 1-13.

Vyas, A., D. Santini, and L. Johnson. 2009. Plug-In Hybrid Electric Vehicles' Potential for Petroleum Use Reduction: Issues Involved in Developing Reliable Estimates, Presented for the 88th Annual Meeting of Transportation Research Board, Washington, D.C.

Waddell. P., A., A. Borning, M. Noth, N. Freier, M. Becke and F. Ulfarsson. 2003. Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. *Networks and Spatial Economics*, 3:43-67.

Wang, M., Y. Wu, and A. Elgowainy. 2007. Operating Manual for GREET: Version 1.7, ANL/ESD/05-3, Center for Transportation Research, Argonne National Laboratory.

Wang, M. 2007. Overview of GREET Model Development at Argonne, Center for Transportation Research, Argonne National Laboratory. http://www.transportation.anl.gov/pdfs/TA/468.pdf. Accessed on June 26th 2007.

Ward's. 2007. *Ward's Automotive Yearbook* 2007. Ward's Communications, Detroit, Michigan.

Wu, Y. 2007. Demonstration of GREET 1.7 Simulations, Center for Transportation Research, Argonne National Laboratory, June 25-26.

Zhao, Y. and K. M. Kockelman. 2002. Household Vehicle Ownership by Vehicle Type: Application of a Multivariate Negative Binomial Model. Proceedings of the Transportation Research Board's 81st Annual Meeting, Washington, DC.

Zhou, B. and K. Kockelman. 2006. Microsimulation of Single-family Residential Land Use for Market Equilibria. Proceedings of the TRB Innovations in Travel Demand Modeling Conference, Austin, Tx.

Zhou, B. and K. Kockelman. 2008. Microsimulation of Residential Land Development and Household Location Choices: Bidding for Land in Austin, Texas. *Transportation Research Record,* 2077: 106-112.

Zhou, B. and K. Kockelman. 2010. Land Use Change through Microsimulation of Market Dynamics: An Agent-based Model of Land Development and Locator Bidding in Austin, Texas. Under Review for *Computers, Environment and Urban Systems.*

APPENDIX A: SURVEY QUESTIONNAIRE

Austin Vehicle Choice Survey
UT Austin Internal Review Board # 2009-03-0095

Dear Respondent,

The Transportation Engineering Program of the Civil Engineering Department at The University of Texas at Austin is conducting a research study to explore vehicle choices, under various energy policies and vehicle technologies.

In today's world of volatile fuel prices and climate concerns, household vehicle ownership and usage patterns are important topics. This research project seeks to better understand the patterns of vehicle ownership and attitudes toward potential policies and technologies.

- The survey will take approximately 15-20 minutes to complete.
- The survey will ask questions about you, your household’s current vehicle inventory, and your future vehicle preferences.
- No names or other identifying information will be used in preparing the data for analysis.
- There are no risks involved in participation in this study and no direct benefits.
- Your input and opinions are **VERY IMPORTANT**, since it is critical that all perspectives and types of residents be represented in this survey.

If you have any questions or comments about this study please feel free to contact me personally at (512) 471-0210. If you have any questions about your rights as a research participant, please contact Jody Jenson, PhD., Chair of UT Austin's Institutional Review Board for the Protection of Human Subjects, (512) 471-8871.

Your completion of the survey indicates your willingness to participate in the study.

Thank you very much for your time and cooperation.

Sincerely,

Dr. Kara Kockelman
Associate Professor of Transportation Engineering & Faculty Sponsor

Section 1- Current and Past Vehicles

If you do not own any vehicles, please skip to Question 3 on this page.

----

1. In order to forecast future vehicle ownership patterns and use, we need to know what **vehicles your household* presently owns**/uses, how many miles have been accumulated on each vehicle and how long they have been held/used. Please indicate the following for each of the vehicles used by your household*. Please look at your vehicle records since the information provided here is vital.

MAKE
MODEL
YEAR of manufacture
Average **MILES** traveled per **year**
YEAR of **ACQUISITION****
Current **ODOMETER** reading
ODOMETER reading at the time of acquisition**

Notes: *A household includes all persons who occupy a housing unit such as a house, an apartment, a mobile home, a group of rooms or a single room. The occupants may be a single family, one person living alone, two or more families living together or any other group of related or unrelated persons who share living arrangements. **Acquisition refers to the date on which your household first obtained the vehicle, by purchase, gift, or leasing.

	Make (example: Toyota)	Model (example: Camry)	Year of manufacture (example: 2005)	Average miles traveled per year (example: 15000)	Year of acquisition (example: 2005)	Current odometer reading (example: 60,000 miles)	Odometer reading at the time of acquisition (example: 0 miles)
1							
2							
3							
4							
5							
6							

2. Are **any** of these vehicles **leased** vehicles? (If so, please indicate the number of the vehicle as listed in **question 1**.)

	Number of the vehicle as listed in question 1
1	_____
2	_____
3	_____
4	_____

3. Over the past **10 years**, how many different passenger vehicles have been registered to you or to any other members of your household? (Please specify a number.)

____

4. Please **check** the names of **all** the manufacturers of passenger vehicles that have been registered to you or to any other members of your household in the past 10 years. (Please include vehicles sold, scrapped, destroyed by a crash or given away.) (If this question does not apply to you, please skip.)

( ) BMW
( ) Chrysler (Chrysler, Dodge and Jeep)
( ) Ford
( ) GM (Buick, Chevrolet, GMC, Hummer, Pontiac, Saab and Saturn)
( ) Honda
( ) Hyundai
( ) Kia
( ) Mazda
( ) Mercedes
( ) Nissan
( ) Toyota
( ) Volkswagen
( ) Volvo
( ) Other

5. How did you **obtain** the vehicle most **recently** acquired by your household?

( ) Purchased new
( ) Purchased used – from used car lot
( ) Purchased used – from family member
( ) Purchased used – from newspaper advertisement
( ) Purchased used – on line
( ) Received free – from family member or friend
( ) Other

6. What **OTHER VEHICLES** did you seriously consider **PURCHASING** during your most recent vehicle purchase? Please indicate the **MAKE** and **MODEL** of those vehicles in the space available.

	Make (example: Toyota)	Model (example: Camry)
Vehicle 1	_____	_____
Vehicle 2	_____	_____

7. What are the most important characteristics that were missing in vehicles not purchased? (Please check only one option relevant to each vehicle.)

	Vehicle 1	Vehicle 2
Fuel economy was too low.	□	□
Purchase price was too high.	□	□
Vehicle type was not really what I wanted (e.g., compact car, SUV, pickup truck, etc).	□	□
Vehicle appearance was not attractive enough.	□	□
Resale value was a concern.	□	□
Maintenance costs were too high.	□	□
Amenities were missing (e.g., sunroof, power windows, GPS (global positioning system), CD/DVD player, etc.).	□	□
Cabin room/interior size was inadequate.	□	□
Safety rating was a concern.	□	□
Manual transmission was a concern.	□	□
Other issue.	□	□

7. What was the other **issue**. Please explain? (Please **skip** the question if the other issue option was not selected above.)

____

8. Did you or your household sell, donate, scrap, lose (to a crash or other accident) or otherwise let go of a vehicle within **12 months (before or after**) of buying your most recent vehicle?

( ) Yes, I/we let go of another vehicle within the past 12 months.

( ) No, I/we did not let go of any other vehicle in that time period.

9. What vehicles have you/or your household sold, lost (to a crash or other accident) or given away in the **PAST**. Please indicate the **MAKE, MODEL, YEAR** of acquisition, approximate **MILES** traveled in the 12 months prior to letting go of the vehicle and **YEAR** of vehicle sale or loss for each of the vehicles used by your household?

	Make (example. Toyota)	**Model** (example. Camry)	**Year of acquisition** (example. 1990)	**Miles traveled per year immediately prior selling or losing or giving away** (example. 10,000 miles)	**Last year of vehicle ownership** (example. 2000)
1					
2					
3					
4					
5					

10. What was the main **REASON** for selling or losing or giving up this/these vehicle/s? (Please check only one option relevant to each vehicle. If you sold or gave up only one vehicle please skip options for the other vehicles.)

	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Maintenance costs too high	◻	◻	◻	◻	◻
Engine problems	◻	◻	◻	◻	◻
Crashed the vehicle	◻	◻	◻	◻	◻
Needed a larger vehicle with more seating	◻	◻	◻	◻	◻
Needed a vehicle with a better fuel economy	◻	◻	◻	◻	◻
Change in household income	◻	◻	◻	◻	◻
Change in family size	◻	◻	◻	◻	◻
Change in home location	◻	◻	◻	◻	◻
Change in employment status	◻	◻	◻	◻	◻
Gave it to my child	◻	◻	◻	◻	◻
Traded in for a new vehicle	◻	◻	◻	◻	◻
Needed a vehicle with more power	◻	◻	◻	◻	◻
Lease ran out	◻	◻	◻	◻	◻
Too many miles on the vehicle	◻	◻	◻	◻	◻
Other issue	◻	◻	◻	◻	◻

11. What was the other issue. Please explain? (Please **skip** the question if the other issue option was not selected above.)

____

12. Which of the following **DECISIONS** are you considering at this time?

( ) I am/we are thinking about **BUYING** a vehicle in the next year.
( ) I am/we are thinking about **SELLING** one or more vehicle/s in the next year.
( ) I/we do **not** intend to **BUY or SELL** our current vehicle/s in the next 12 months.

13. Please indicate the **MAKE**, **MODEL** for any vehicles you are presently considering **SELLING** or indicate the **number** of the vehicle as listed in **question 1**.

	Make (example.Toyota)	Model (example. Camry)	Number of the vehicle as listed in question1
1	____________	____________	__________
2	____________	____________	__________
3	____________	____________	__________

14. If you had to **buy a vehicle** in the next 12 months, would you buy a **new or used vehicle**?

( ) I would definitely buy a **NEW** vehicle.
( ) I would probably buy a **NEW** vehicle.
( ) I **dont know** whether the purchased vehicle would be NEW or USED.
( ) I would **probably** buy a **USED** vehicle.
( ) I would **definitely** buy a **USED** vehicle.

15. Do you have any **comments** about or **issues** with the questions asked? Please describe.

____
____
____

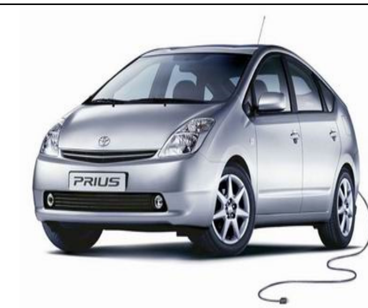
Section 2 - Consumer Vehicle Choice Preference

16. If you had to **BUY** or **LEASE** a new vehicle in the coming month, and could choose only from among the following, **which would you BUY** or LEASE? (**Note**: The **Fuel Economy** in miles per gallon (mpg) and **Purchase Price** in dollars for **each** of the different vehicles are given below. Please **select** only **one** of the following by clicking on the photo. For more information on these vehicles, please click on the link below each photo.)

 Fuel Economy: 15 mpg Purchase Price: $29,000 *Ford F-150* ☐	 Fuel Economy: 22 mpg Purchase Price: $34,500 *Lexus ES 350* ☐	 Fuel Economy: 22 mpg Purchase Price: $31,000 *Nissan Maxima* ☐	 Fuel Economy: 46 mpg Purchase Price: $25,000 *Toyota Prius* ☐
 Fuel Economy: 20 mpg Purchase Price: $28,000 *Nissan Murano* ☐	 Fuel Economy: 16 mpg Purchase Price: $61,500 *Hummer* ☐	 Fuel Economy: 23 mpg Purchase Price: $20,500 *Ford Escape* ☐	 Fuel Economy: 45 mpg* Purchase Price: $33,000 *Plug-In Hybrid Prius* ☐

 Fuel Economy: 18 mpg Purchase Price: $28,500 *Honda Odyssey* ☐	 Fuel Economy: 29 mpg Purchase Price: $19,000 *Honda Civic* ☐	 Fuel Economy: 31 mpg Purchase Price: $15,000 *Toyota Yaris* ☐	 Fuel Economy: 36 mpg Purchase Price: $17,000 *Smart Car* ☐

17. Imagine that **GASOLINE PRICES** are hovering at **$5 per gallon** and stay there for several more years. If you had to BUY or LEASE a new vehicle in the coming month, and could choose only from the following, which would you BUY or LEASE? (**Note**: The **Annual Fuel Costs** for driving **15,000 miles** each year and **Purchase Price** in dollars for each of the different vehicles are given below. Please **select** only **one** of the following by clicking on the photo. For more information on these vehicles please click on the link below each photo.)

 Fuel Costs: $4,125/year Purchase Price: $29,000 *Ford F-150* ☐	 Fuel Costs: $3,250/year Purchase Price: $34,500 *Lexus ES 350* ☐	 Fuel Costs: $2,875/year Purchase Price: $31,000 *Nissan Maxima* ☐	 Fuel Costs: $1,375/year Purchase Price: $25,000 *Toyota Prius* ☐
 Fuel Costs: $3,625/year Purchase Price: $28,000 *Nissan Murano* ☐	 Fuel Costs: $3,875/year Purchase Price: $61,500 *Hummer* ☐	 Fuel Costs: $2,875/year Purchase Price: $31,000 *Ford Escape* ☐	 Fuel Costs: $775/year Purchase Price: $33,000 *Plug-In Hybrid Prius* ☐

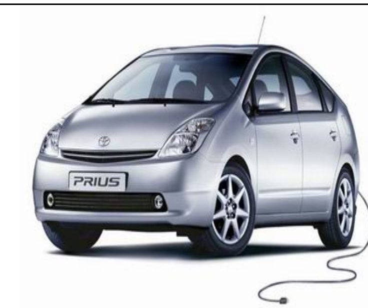
			
Fuel Costs: $4,125/year Purchase Price: $28,500 *Honda Odyssey* ☐	Fuel Costs: $2,125/year Purchase Price: $19,000 *Honda Civic* ☐	Fuel Costs: $2,000/year Purchase Price: $15,000 *Toyota Yaris* ☐	Fuel Costs: $2,000/year Purchase Price: $17,000 *Smart Car* ☐

18. Imagine now that **GASOLINE PRICES** are instead hovering at **$7 per gallon** and stay there for several more years. If you had to BUY or LEASE a new vehicle in the coming month, and could choose only from the following, which would you **BUY** or **LEASE**? (**Note**: The **Annual Fuel Costs** for driving **15,000 miles** each year and **Purchase Price** in dollars for **each** of the different vehicles are given below. Please **select** only **one** of the following by clicking on the photo. For more information on these vehicles please click on the link below each photo.)

 Fuel Costs: $5,775/year Purchase Price: $29,000 *Ford F-150* □	 Fuel Costs: $4,550/year Purchase Price: $34,500 *Lexus ES 350* □	 Fuel Costs: $4,025/year Purchase Price: $31,000 *Nissan Maxima* □	 Fuel Costs: $1,925/year Purchase Price: $25,000 *Toyota Prius* □
 Fuel Costs: $5,075/year Purchase Price: $28,000 *Nissan Murano* □	 Fuel Costs: $5,425/year Purchase Price: $61,500 *Hummer* □	 Fuel Costs: $3,850/year Purchase Price: $20,500 *Ford Escape* □	 Fuel Costs: $1000/year Purchase Price: $33,000 *Plug-In Hybrid Prius* □

			
Fuel Costs: $5,775/year Purchase Price: $28,500 *Honda Odyssey* ☐	Fuel Costs: $2,975/year Purchase Price: $19,000 *Honda Civic* ☐	Fuel Costs: $2,800/year Purchase Price: $15,000 *Toyota Yaris* ☐	Fuel Costs: $2,900/year Purchase Price: $17,000 *Smart Car* ☐

19. Different vehicles have different **environmental consequences**. The U.S Environmental Protection Agency, U.S Department of Energy and researchers have estimated costs of various vehicle emissions. The following table uses such estimates to put monetary values on the **Global Warming** and **Health Impacts** of different vehicles. Given such estimates, **which would you BUY** or **LEASE**? (Estimates of these **external costs** (imposed on others) for driving **15,000 miles** each year and **purchase price** for **each** of the different vehicles are given below.) Please **select** only **one** of the following by clicking on the photo. For information on the cost estimates for each for these vehicles please click here.

 $740/year $29,000 *Ford F-150* ☐	 $480/year $34,500 *Lexus ES 350* ☐	 $495/year $31,000 *Nissan Maxima* ☐	 $240/year $25,000 *Toyota Prius* ☐
 $540/year $28,000 *Nissan Murano* ☐	 $965/year $61,500 *Hummer* ☐	 $620/year $20,500 *Ford Escape* ☐	 $79/year $33,000 *Plug-In Hybrid Prius* ☐

 $750/year $28,500 *Honda Odyssey* □	 $375/year $19,000 *Honda Civic* □	 $350/year $15,000 *Toyota Yaris* □	 $300/year $17,000 *Smart Car* □

20. Do you have any **comments** or **issues** about the questions asked? Please describe.

____
____
____
____
____

Section 3 - Vehicle Policy

21. Consider a new policy where **REBATES** are given to those purchasing relatively fuel **EFFICIENT** vehicles and **FEES** are charged on the purchase of relatively **INEFFICIENT** vehicles. Assume the amounts vary with fuel economy, as shown in the chart below. How do you feel about such a policy?

Fuel Economy (in miles per gallon)	**Rebate+/Fee-**
More than 40 MPG	$ 3,000 (**rebate**)
40 MPG	$ 2,000 (**rebate**)
35 MPG	$ 1,000 (**rebate**)
30 MPG	$ 0 (**no fee/no rebate**)
25 MPG	-$ 1,000 (**fee**)
20 MPG	-$ 2,000 (**fee**)
15 MPG	-$ 3,000 (**fee**)
less than 10 MPG	-$ 4,000 (**fee**)

( ) I **strongly oppose** this policy.
( ) I **somewhat oppose** this policy.
( ) I am **neutral** regarding this policy.
( ) I **somewhat support** this policy.
( ) I **strongly support** this policy.

22. Does your residential unit have a garage or a carport with **access** to **electricity** which can be used to charge a plug-in hybrid vehicle (**PHEV**)?
( ) Yes
( ) No

23. If **gasoline prices rise** to **$6** per gallon and stay there, would you do any of the following?
( ) Pay an additional $2,500 to buy a hybrid version of your vehicle in order to reduce your gasoline use by 30%.
( ) Pay an additional $4,000 to buy a plug-in hybrid version of your vehicle, in order to reduce your gasoline use by 45% (assuming you travel about 20 miles per day on its battery only.)
( ) Adapt to the change.
( ) Don't know what I would do.
( ) Other

24. How would you adapt to the change when **gasoline prices rise** to **$6** per gallon and stay there? (Please check a**ll the apply**.)

( ) Use public transportation more
( ) Carpool more often
( ) Walk/Bike more to nearby places rather than using the vehicle
( ) Cut back on other expenditures
( ) Other

25. Suppose you are going to buy a new vehicle today, and the **hybrid gasoline/electric** version vehicle costs **$3,000** more than the standard model of the same vehicle. Would you still seriously consider buying it?

( ) Yes, I would seriously consider buying it even if, it costs $3,000 more.
( ) I would not consider such an option.
( ) I have no opinion on this.
( ) Other

26. Under current **gasoline price uncertainties**, would your household consider buying a **plug-in hybrid electric vehicle** (PHEV)? Such vehicles generally require battery re-charging after moderate use and cost $6,000 more than a comparable gas-powered vehicle. But they are expected to save owners 50% or more in fuel costs and will likely be made available in the make & model of a Toyota Camry, Ford Focus, Chevy Malibu, Ford Escape, Honda Odyssey and others.

( ) Yes, I/we would consider buying such a vehicle.
( ) No, I/we would not consider buying such a vehicle.

27. If you were **considering purchasing a new vehicle today**, please **RANK the three most important characteristics**, according to their priority level (with first priority being most important to you, and third priority being the third most important to you).

	Characteristics
First priority	_____
Second priority	_____
Third priority	_____

28. Do you have any **comments** about or **issues** with the questions asked? Please describe.

____
____
____

Section 4 - Demographics

29. Including yourself, **HOW MANY PEOPLE** live in your household? (Please do not include anyone who usually lives somewhere else or is just visiting, such as a college student away at school.)

( ) One (1)
( ) Two (2)
( ) Three (3)
( ) Four or more (4+) (Please specify exact number.) _____________

30. Including yourself, how many **WORKERS** usually live in your home? (Please include all the persons in your household who get paid for working full-time, part-time or are self-employed.)

( ) Zero (0)
( ) One (1)
( ) Two (2)
( ) Three (3)
( ) Four or more (4+) (Please specify exact number.) ______________

31. What is your **AGE**?

( ) Less than 25 years old
( ) 25-34
( ) 35-44
( ) 45-54
( ) 55-64
( ) 65 or more years of age

32. Which of the following best describes your household's **TOTAL annual INCOME** from all sources, before taxes, for all members of your household in 2008? (Income data is very important for developing models that predict vehicle ownership behavior and thus changes in vehicle composition of households over time.)

( ) Less than $10,000
( ) $10,000-19,999
( ) $20,000-29,999
( ) $30,000-39,999
( ) $40,000-49,999
( ) $50,000-59,999
( ) $60,000-74,999
( ) $75,000-99,999
( ) $100,000-124,999
( ) $125,000-149,999
( ) $150,000-199,999
( ) $200,000 or more

33. Are you male or female?

( ) Male
( ) Female

34. Which of the following best describes your **ETHNICITY**?

( ) Hispanic
( ) Asian
( ) African American
( ) Caucasian/White
( ) Other (Please specify.)

35. Do you have a valid **DRIVERS LICENSE**?

( ) Yes
( ) No

36. Are you currently enrolled as a **STUDENT**?

( ) No, I am not a student.
( ) Yes, I am enrolled full-time (12 or more credit hours this semester).
( ) Yes, I am enrolled part-time (less than 12 credit hours).

37. Which of the following best describes your **EMPLOYMENT STATUS**?

( ) I work full-time (35 hours or more per week).
( ) I work part-time (less than 35 hours per week).
( ) I am a homemaker.
( ) I am self-employed.
( ) I am unemployed, but looking for employment.
( ) I am unemployed, and not looking for employment.
( ) I am retired.

38. What is the highest level of **EDUCATION** you have completed?

( ) Did not complete high school
( ) High school (or equivalent)
( ) Associate's or technical degree (or equivalent)
( ) Bachelor's degree
( ) Master's degree or higher

39. What is your **HOME ADDRESS**? (For privacy reasons, you may wish to use XX to represent the last two digits of the street number. Also, please include your zip code. Example: 12XX E. Dean Keeton St., 78722, instead of 1234 E. Dean Keeton St., 78722.) (Location data is very useful here because neighborhood form impacts vehicle preferences. Please note that all information will be kept highly confidential.)

____

40. We would like to send you a copy of our report, if that is of interest to you, and to contact you with any follow-up questions we may have. (This is especially helpful if we need to clarify an answer provided here.) Please allow us to do that by providing your email address. Thank you.

____

41. Do you have any comments or suggestions for us?

____
____
____
____
____

Thank you for completing our survey!!

APPENDIX B: ESTIMATION OF FUEL AND ENVIRONMENTAL COSTS FOR A PHEV30

Fuel Cost Estimation

Fuel Costs					
Case 1 : 41 miles/day for 365 days in a year					
	Split	Total miles	Fuel costs (@9cents per kWh and $2.5 per gallon)	Fuel costs (@9cents per kWh and $5 per gallon)	Fuel costs (@9cents per kWh and $7 per gallon)
Electric range (250 kWh per mile)	30	10950	246.3	246.4	246.4
Gasoline range (45 miles per gallon)	11	4015	223.1	446.1	624.5
Total Fuel Costs ($/vehicle)			469.4	692.5	870.9

Fuel Costs					
Case 2 : 50 miles/day for 300 days					
	Split	Total miles	Fuel costs (@9cents per kWh and $2.5 per gallon)	Fuel costs (@9cents per kWh and $5 per gallon)	Fuel costs (@9cents per kWh and $7 per gallon)
Electric range (250 kWh per mile)	30	9000	202.5	202.5	202.5
Gasoline range (45 miles per gallon)	20	6000	333.3	666.7	933.3
Total Fuel Costs ($/vehicle)			535.8	869.2	1135.8

Global warming costs and health costs (externality costs) for a PHEV30 in the gasoline drive mode were created using Lemp and Kockelman's (2008) estimates. EIA's (2002) estimates of pollution from electricity generation coupled with Small and Kazimi's (1995) morbidity and mortality costs by pollutant type gave the externality costs for the PHEV30 in electric drive mode. The externality costs for both the driving modes are as follows: 1.58E-02 (gasoline mode) and 9.27E-05 (electric mode).

Environmental Cost Estimation

Environmental Costs				
Case 1 : 41 miles/day for 365 days in a year				
	Split	Total miles	Total kWh used	Annual emissions costs
Electric range (250 KwH per mile)	30	10950	2737.5	0.2540
Gasoline range (45 miles per gallon)	11	4015	--	63.400
Total Environmental Costs ($/vehicle)				63.654

Environmental Costs				
Case 1 : 50 miles/day for 300 days				
	Split	Total miles	Total kWh used	Annual emissions costs
Electric range (250 KwH per mile)	30	9000	2250.0	0.208
Gasoline range (45 miles per gallon)	20	6000		94.733
Total Environmental Costs ($/vehicle)				94.941

APPENDIX C: SURVEY RESPONSES

The tables included here are the raw shares and are unweighted.

Sample Versus PUMS and Associated Weights for Gender, Student and Worker Status and AGE

		Frequencies	
Variable	Variable Response	PUMS	Sample
Gender	Male	22,593	415
	Female	22,960	230
Student Status	Student	5,954	245
	Non-Student	39,599	400
Worker Status	Worker	30,816	551
	Non-Worker	14,737	94
Age	18 to 25 years	7,412	170
	25 to 34	10,181	183
	35 to 44	10,352	89
	45 to 54	7,845	96
	55 to 64	4,338	82
	65 or more	5,425	26
Household Size	1	7,669	215
	2	14,459	223
	3	8,407	88
	4	7,831	85
	5+	7,187	34
Income	Low	12,017	144
	Middle	19,459	190
	High	14,077	311

Mutlidimensional Weights Matrix

Gender (Female=1,Male =0)	Age	Emp Status (1=worker,0=nonworker)	Student status (1=student,0=otherwise)	HHsize Categories	Income Categories	Count in Sample	Count in PUMS	Sample Proportion	PUMS Proportion	Weights
0	1	0	0	1	1	5	414	0.0078	0.0091	1.1724
0	1	0	0	1	2	1	2	0.0016	0.0000	0.0283
0	1	0	0	2	1	3	175	0.0047	0.0038	0.8260
0	1	0	0	2	2	1	83	0.0016	0.0018	1.1753
0	1	0	0	3	1	1	136	0.0016	0.0030	1.9257
0	1	0	0	3	2	2	85	0.0031	0.0019	0.6018
0	1	0	0	3	3	2	43	0.0031	0.0009	0.3044
0	1	0	0	4	2	4	316	0.0062	0.0069	1.1186
0	1	0	0	5	3	3	166	0.0047	0.0036	0.7835
0	1	1	0	1	1	32	360	0.0496	0.0079	0.1593
0	1	1	0	1	2	6	17	0.0093	0.0004	0.0401
0	1	1	0	1	3	1	9	0.0016	0.0002	0.1274
0	1	1	0	2	2	6	267	0.0093	0.0059	0.6301
0	1	1	0	2	3	3	44	0.0047	0.0010	0.2077
0	1	1	0	3	1	4	143	0.0062	0.0031	0.5062
0	1	1	0	3	2	2	206	0.0031	0.0045	1.4584
0	1	1	0	3	3	7	74	0.0109	0.0016	0.1497
0	1	1	0	4	1	1	122	0.0016	0.0027	1.7275
0	1	1	0	4	2	1	172	0.0016	0.0038	2.4355
0	1	1	0	4	3	12	126	0.0186	0.0028	0.1487
0	1	1	0	5	2	1	178	0.0016	0.0039	2.5204
0	1	1	0	5	3	8	134	0.0124	0.0029	0.2372
0	2	0	0	1	1	1	61	0.0016	0.0013	0.8637
0	2	0	0	2	1	1	72	0.0016	0.0016	1.0195

0	2	0	0	2	2	1	79	0.0016	0.0017	1.1186
0	2	0	0	3	2	1	294	0.0016	0.0065	4.1629
0	2	0	0	4	3	1	803	0.0016	0.0176	11.3702
0	2	1	0	1	1	22	210	0.0341	0.0046	0.1352
0	2	1	0	1	2	16	197	0.0248	0.0043	0.1743
0	2	1	0	2	1	3	285	0.0047	0.0063	1.3452
0	2	1	0	2	2	21	638	0.0326	0.0140	0.4302
0	2	1	0	2	3	11	394	0.0171	0.0086	0.5072
0	2	1	0	3	2	6	417	0.0093	0.0092	0.9841
0	2	1	0	3	3	12	235	0.0186	0.0052	0.2773
0	2	1	0	4	1	2	75	0.0031	0.0016	0.5310
0	2	1	0	4	2	1	367	0.0016	0.0081	5.1966
0	2	1	0	4	3	4	722	0.0062	0.0159	2.5558
0	3	0	0	1	1	1	83	0.0016	0.0018	1.1753
0	3	0	0	2	2	1	118	0.0016	0.0026	1.6708
0	3	0	0	2	3	1	51	0.0016	0.0011	0.7221
0	3	0	0	3	2	1	1114	0.0016	0.0245	15.7738
0	3	1	0	1	1	3	216	0.0047	0.0047	1.0195
0	3	1	0	1	2	5	330	0.0078	0.0072	0.9345
0	3	1	0	1	3	3	122	0.0047	0.0027	0.5758
0	3	1	0	2	2	2	389	0.0031	0.0085	2.7541
0	3	1	0	2	3	10	315	0.0155	0.0069	0.4460
0	3	1	0	3	2	1	377	0.0016	0.0083	5.3382
0	3	1	0	3	3	7	337	0.0109	0.0074	0.6817
0	3	1	0	4	2	2	463	0.0031	0.0102	3.2780
0	3	1	0	4	3	9	485	0.0140	0.0106	0.7630
0	3	1	0	5	1	1	79	0.0016	0.0017	1.1186
0	3	1	0	5	3	9	1263	0.0140	0.0277	1.9871

0	4	0	0	1	1	2	77	0.0031	0.0017	0.5451
0	4	0	0	1	2	2	15	0.0031	0.0003	0.1062
0	4	0	0	1	3	1	5	0.0016	0.0001	0.0708
0	4	1	0	1	1	1	427	0.0016	0.0094	6.0462
0	4	1	0	1	2	4	199	0.0062	0.0044	0.7044
0	4	1	0	1	3	3	112	0.0047	0.0025	0.5286
0	4	1	0	2	1	1	132	0.0016	0.0029	1.8691
0	4	1	0	2	2	4	516	0.0062	0.0113	1.8266
0	4	1	0	2	3	11	468	0.0171	0.0103	0.6024
0	4	1	0	3	2	3	287	0.0047	0.0063	1.3546
0	4	1	0	3	3	6	345	0.0093	0.0076	0.8142
0	4	1	0	4	2	2	148	0.0031	0.0032	1.0478
0	4	1	0	4	3	12	270	0.0186	0.0059	0.3186
0	4	1	0	5	2	1	257	0.0016	0.0056	3.6390
0	5	0	0	1	2	2	132	0.0031	0.0029	0.9345
0	5	0	0	2	1	1	251	0.0016	0.0055	3.5541
0	5	0	0	2	2	2	276	0.0031	0.0061	1.9540
0	5	0	0	2	3	5	214	0.0078	0.0047	0.6060
0	5	0	0	3	2	1	113	0.0016	0.0025	1.6000
0	5	0	0	4	3	1	114	0.0016	0.0025	1.6142
0	5	1	0	1	1	1	126	0.0016	0.0028	1.7841
0	5	1	0	1	2	5	110	0.0078	0.0024	0.3115
0	5	1	0	1	3	3	96	0.0047	0.0021	0.4531
0	5	1	0	2	2	5	595	0.0078	0.0131	1.6850
0	5	1	0	2	3	23	1256	0.0357	0.0276	0.7732
0	5	1	0	3	3	7	142	0.0109	0.0031	0.2872
0	6	0	0	1	3	1	59	0.0016	0.0013	0.8354
0	6	0	0	2	2	1	887	0.0016	0.0195	12.5596
0	6	0	0	2	3	7	649	0.0109	0.0142	1.3128

0	6	0	0	5	3	1	54	0.0016	0.0012	0.7646
0	6	1	0	1	1	1	132	0.0016	0.0029	1.8691
0	6	1	0	1	3	1	11	0.0016	0.0002	0.1558
0	6	1	0	2	2	1	234	0.0016	0.0051	3.3134
0	6	1	0	2	3	6	35	0.0093	0.0008	0.0826
0	6	1	0	3	3	2	22	0.0031	0.0005	0.1558
0	6	1	0	4	3	2	30	0.0031	0.0007	0.2124
1	1	0	1	1	1	6	443	0.0093	0.0097	1.0455
1	1	0	0	2	1	3	157	0.0047	0.0034	0.7410
1	1	0	1	2	3	1	271	0.0016	0.0059	3.8373
1	1	0	1	4	3	1	243	0.0016	0.0053	3.4408
1	1	0	1	5	3	1	63	0.0016	0.0014	0.8921
1	1	1	1	1	1	16	329	0.0248	0.0072	0.2912
1	1	1	1	1	2	6	55	0.0093	0.0012	0.1298
1	1	1	1	1	3	2	5	0.0031	0.0001	0.0354
1	1	1	1	2	1	4	242	0.0062	0.0053	0.8567
1	1	1	1	2	2	6	289	0.0093	0.0063	0.6820
1	1	1	1	3	3	3	593	0.0047	0.0130	2.7989
1	1	1	1	4	1	1	99	0.0016	0.0022	1.4018
1	1	1	1	4	3	3	837	0.0047	0.0184	3.9505
1	2	0	1	1	1	1	296	0.0016	0.0065	4.1913
1	2	0	1	2	1	2	254	0.0031	0.0056	1.7983
1	2	0	1	2	2	2	74	0.0031	0.0016	0.5239
1	2	0	1	2	3	2	226	0.0031	0.0050	1.6000
1	2	1	1	1	1	12	515	0.0186	0.0113	0.6077
1	2	1	1	1	2	12	333	0.0186	0.0073	0.3929
1	2	1	1	1	3	1	51	0.0016	0.0011	0.7221
1	2	1	1	2	1	3	308	0.0047	0.0068	1.4537
1	2	1	1	2	2	14	764	0.0217	0.0168	0.7727
1	2	1	1	2	3	14	425	0.0217	0.0093	0.4298

1	2	1	1	3	2	1	508	0.0016	0.0112	7.1931
1	2	1	1	3	3	3	304	0.0047	0.0067	1.4348
1	2	1	1	4	2	2	418	0.0031	0.0092	2.9594
1	2	1	1	4	3	3	259	0.0047	0.0057	1.2224
1	2	1	1	5	2	1	393	0.0016	0.0086	5.5647
1	2	1	1	5	3	2	393	0.0031	0.0086	2.7824
1	3	0	1	1	3	1	77	0.0016	0.0017	1.0903
1	3	1	1	1	2	3	725	0.0047	0.0159	3.4219
1	3	1	1	1	3	2	99	0.0031	0.0022	0.7009
1	3	1	1	2	1	1	306	0.0016	0.0067	4.3329
1	3	1	1	2	2	2	420	0.0031	0.0092	2.9735
1	3	1	1	2	3	9	384	0.0140	0.0084	0.6041
1	3	1	1	3	3	3	816	0.0047	0.0179	3.8514
1	3	1	1	4	2	2	568	0.0031	0.0125	4.0213
1	3	1	1	4	3	4	1080	0.0062	0.0237	3.8231
1	3	1	1	5	3	5	734	0.0078	0.0161	2.0786
1	4	0	1	2	1	1	159	0.0016	0.0035	2.2514
1	4	0	1	2	3	1	125	0.0016	0.0027	1.7700
1	4	0	1	4	3	2	109	0.0031	0.0024	0.7717
1	4	1	1	1	2	9	391	0.0140	0.0086	0.6152
1	4	1	1	1	3	5	170	0.0078	0.0037	0.4814
1	4	1	1	2	2	3	465	0.0047	0.0102	2.1947
1	4	1	1	2	3	9	499	0.0140	0.0110	0.7851
1	4	1	1	3	2	2	340	0.0031	0.0075	2.4071
1	4	1	1	3	3	6	450	0.0093	0.0099	1.0620
1	4	1	1	4	2	1	248	0.0016	0.0054	3.5116
1	4	1	1	4	3	5	611	0.0078	0.0134	1.7303
1	4	1	1	5	3	1	325	0.0016	0.0071	4.6019
1	5	0	1	1	3	1	241	0.0016	0.0053	3.4125
1	5	0	1	2	3	2	308	0.0031	0.0068	2.1806

1	5	1	1	1	1	1	51	0.0016	0.0011	0.7221
1	5	1	1	1	2	4	70	0.0062	0.0015	0.2478
1	5	1	1	1	3	3	106	0.0047	0.0023	0.5003
1	5	1	1	2	2	2	355	0.0031	0.0078	2.5133
1	5	1	1	2	3	3	412	0.0047	0.0090	1.9446
1	5	1	1	3	2	1	122	0.0016	0.0027	1.7275
1	5	1	1	3	3	4	2300	0.0062	0.0505	8.1418
1	6	0	1	1	2	2	71	0.0031	0.0016	0.5027
1	6	1	1	2	3	2	242	0.0031	0.0053	1.7133
0	1	0	1	4	3	7	61	0.0109	0.0013	0.1234
0	1	1	1	2	1	6	284	0.0093	0.0062	0.6702
0	2	1	1	1	3	5	22	0.0078	0.0005	0.0623
Total						645	4555 3	1	1	1

Current vehicle class distribution

Vehicle Class	Share
CUV	5.57
Large Car	2.85
Luxury Car	8.83
Mid-sized Car	32.20
Pick-up Truck	10.33
Compact Car	12.63
Sub-compact Car	6.25
SUV	13.45
Van	7.88
Number of Observations	1002

Type of most recent vehicle acquisition

Options	Shares
New	44.41
Used-car lot, Newspaper or online advertisement	40.40
Used-family or friends	15.19
Number of observations	599

Most important characteristics missing in vehicles not purchased

Options	Shares
Fuel economy was too low	18.31
Purchase price was too high	45.06
Vehicle type was not really what I wanted	12.64
Vehicle appearance was not attractive enough	11.99
Resale value concern	7.46
Maintenance costs too high	9.08
Amenities were missing	9.40
Cabin room was inadequate	13.94
Safety rating was a concern	4.86
Manual transmission was a concern	1.46

Indicator for letting go of a vehicle within 12 months of a recent vehicle purchase

Options	Shares
Yes	46.90
No	53.10
Number of observations	597

Reasons for giving up vehicles in the past

Options	Shares
Too many miles on the vehicle	15.71
Needed a vehicle with more power	4.29
Traded in for a new vehicle	25.71
Gave it to my child	1.07
Change in employment status	2.86
Change in home location	7.86
Change in family size	8.93
Change in household income	2.86
Needed a vehicle with a better fuel economy	20.36
Totaled the vehicle	19.64
Engine problems	24.64
Maintenance costs too high	30.36
Number of Observations	260

Future transaction decision stated choice

Decision	Share
Buy	22
Sell	5.2
Donothing	72.8
Number of observations	599

Type of desired vehicle acquisition

Options	**Shares**
Definitely buy a NEW vehicle	0.15
Probably buy a NEW vehicle	0.24
Don't Know	0.19
Probably buy a USED vehicle	0.22
Definitely buy a USED vehicle	0.19
Number of observations	602

Stated preference choices

	TREND	Gas at $5 per gallon	Gas at $7 per gallon	Environmental external costs
Compact	25.60	22.02	15.72	22.61
Sub compact	12.18	13.07	11.40	7.82
Large car	2.55	2.56	0.73	2.99
Luxury car	4.23	1.77	1.14	2.83
Smart car	6.18	3.50	3.44	4.56
HEV	20.20	26.51	26.59	19.38
PHEV	10.82	14.66	29.08	24.74
Van	6.16	5.58	5.27	5.36
SUV	5.03	6.39	3.56	4.50
CUV	2.95	1.66	1.02	1.68
Pick up truck	3.16	1.68	1.37	3.03
Hummer	0.93	0.61	0.68	0.49

Opinion on FEEBATE

Options	**Shares**
Strongly Oppose	15
Somewhat Oppose	14
Neutral	8
Somewhat Support	30
Strongly Support	33
Number of observations	600

Access to electricity near residential unit

Options	**Shares**
Car port	55.03
Number of observations	503

Top three characteristics in vehicle purchase

	First priority	Second priority	Third priority
Fuel economy	18.52	29.94	27.81
Purchase price	29.83	24.12	20.08
Vehicle type/class	21.46	5.75	6.17
Overall visual appeal	1.92	3.31	5.52
Reliability	12.19	21.20	20.90
Resale value	0.10	0.56	1.59
Maintenance cost	1.12	4.75	6.98
Amenities	0.12	2.66	3.79
Cabin room/interior size	5.84	2.84	3.86
Other	8.90	4.86	3.32
Number of observations		524	

Demographics

Variable	**Minimum**	**Maximum**	**Average**
Number of vehicles	0	6	1.706
Number of persons per household	1	7	2.246
Number of workers per household	0	5	1.577
Age	20	70	37.13
Female indicator	0	1	0.358
Income ($/year)	5,000	200,000	80,368

APPENDIX D: MATLAB CODE

This MATLAB code includes only the vehicle fleet evolution code for year 1. Household Evolution code was taken from Tirumalachetty (2009) AND is not included here.

```
clear all;
hnew=dlmread('C:\Documents and Settings\setup-01\Desktop\DESKTOP OLD\microsimulation\hh_1.dat');
supp=dlmread('C:\Documents and Settings\setup-01\Desktop\DESKTOP OLD\microsimulation\vehtype allotment\year1\densitydata_1.xls');
hold=dlmread('C:\Documents and Settings\setup-01\Desktop\test\baseyear_synthetic_evolved.dat');
[a,b]=size(hnew);
[c,d]=size(supp);
[e,f]=size(hold);
veh=zeros(a,42);
util=zeros(a,40);
utility=zeros(a,40);

for i=1:a
   for j=1:e
      if hnew(i,1)==hold(j,1)
         %carrying forward all the evolved household char's through
         %microsimulation models
         veh(i,1)=hnew(i,1);
         veh(i,20)=hnew(i,1);
         veh(i,2)=hnew(i,3);
         veh(i,4)=hnew(i,18);
         veh(i,5)=hnew(i,4);

         veh(i,21)=hnew(i,2);
         veh(i,23)=hnew(i,27);
         veh(i,24)=hnew(i,26);


         veh(i,7:19)=hold(j,7:19);%carrying forward all vehicle char's from base year population through vehicle fleet evolution model
         veh(i,25:37)=hold(j,25:37);
         veh(i,40)=hold(j,40);
      end
   end
   % for new population copying household characteristics
   veh(i,1)=hnew(i,1);
   veh(i,20)=hnew(i,1);
   veh(i,2)=hnew(i,3);
   veh(i,4)=hnew(i,18);
```

```
   veh(i,5)=hnew(i,4);
   veh(i,7)=hnew(i,6);
   veh(i,21)=hnew(i,2);
   veh(i,23)=hnew(i,27);
   veh(i,24)=hnew(i,26);

   if hnew(i,3)>=4
      veh(i,39)=1;
   else
      veh(i,39)=0;
   end

   if hnew(i,3)>=5
      veh(i,41)=1;
   else
      veh(i,41)=0;
   end

   if hnew(i,4)>=80000
      veh(i,42)=1;
   else
      veh(i,42)=0;
   end

   %veh type allotment for new population based on household
   %characteristics
   util(i,1)= exp(-8.5148*(2.5/18.08)+5.57*(0.26932)-0.4148+0.2632*veh(i,24));
   util(i,2)= exp(-8.513*(2.5/17.57)+5.57*(0.30734)+0.0161*veh(i,22)-0.28944*veh(i,2));
   util(i,3)=                    exp(-8.513*(2.5/18.61)+5.57*(0.48004)-1.1211+0.0161*veh(i,22)-
0.28944*veh(i,2));
   util(i,4)=exp(-8.513*(2.5/19)+5.57*(0.25614)+0.0161*veh(i,22)-
0.28944*veh(i,2)+0.6656*veh(i,4)+0.1864*veh(i,23));
   util(i,5)=exp(-8.513*(2.5/15.18)+5.57*(0.27411)+0.0161*veh(i,22)-0.28944*veh(i,2));
   util(i,6)=exp(-8.513*(2.5/14.61)+5.57*(0.26285)+0.0161*veh(i,22)-0.28944*veh(i,2));
   util(i,7)=exp(-8.513*(2.5/20.65)+5.57*(0.29577)+0.0161*veh(i,22)-0.28944*veh(i,2));
   util(i,8)=exp(-
8.513*(2.5/26.6)+5.57*(0.16726)+0.8756*veh(i,39)+0.26323*veh(i,24)+0.0161*veh(i,22)-
0.28944*veh(i,2));
   util(i,9)=exp(-8.513*(2.5/15.1)+5.57*(0.35221)+0.0161*veh(i,22)-0.28944*veh(i,2));
   util(i,10)=sum(util(i,1:9));
   util(i,11)=util(i,1)/util(i,10);
   util(i,12)=(util(i,2)+util(i,1))/util(i,10);
   util(i,13)=(util(i,2)+util(i,1)+util(i,3))/util(i,10);
   util(i,14)=(util(i,2)+util(i,1)+util(i,3)+util(i,4))/util(i,10);
   util(i,15)=(util(i,2)+util(i,1)+util(i,3)+util(i,4)+util(i,5))/util(i,10);
   util(i,16)=(util(i,2)+util(i,1)+util(i,3)+util(i,4)+util(i,5)+util(i,6))/util(i,10);
```

```
   util(i,17)=(util(i,2)+util(i,1)+util(i,3)+util(i,4)+util(i,5)+util(i,6)+util(i,7))/util(i,10);
   util(i,18)=(util(i,2)+util(i,1)+util(i,3)+util(i,4)+util(i,5)+util(i,6)+util(i,7)+util(i,8))/util(i,10);

util(i,19)=(util(i,2)+util(i,1)+util(i,3)+util(i,4)+util(i,5)+util(i,6)+util(i,7)+util(i,8)+util(i,9))/util(i,
10);
      if veh(i,7)>0
         for v=1:veh(i,7)
            y(v)=rand;
            if y(v)<util(i,11)
               veh(i,8+v-1)=1;
               veh(i,26+2*(v-1))=18.08;
               veh(i,27+2*(v-1))=0.26932;
            elseif y(v)>util(i,11) && y(v)< util(i,12)
               veh(i,8+v-1)=2;
               veh(i,26+2*(v-1))=17.57;
               veh(i,27+2*(v-1))=0.30734;
            elseif y(v)>util(i,12) && y(v)< util(i,13)
               veh(i,8+v-1)=3;
               veh(i,26+2*(v-1))=18.61;
               veh(i,27+2*(v-1))=0.48004;
            elseif y(v)>util(i,13) && y(v)< util(i,14)
               veh(i,8+v-1)=4;
               veh(i,26+2*(v-1))=19;
               veh(i,27+2*(v-1))=0.25614;
            elseif y(v)>util(i,14) && y(v)< util(i,15)
               veh(i,8+v-1)=5;
               veh(i,26+2*(v-1))=14.67;
               veh(i,27+2*(v-1))=0.27411;
            elseif y(v)>util(i,15) && y(v)< util(i,16)
               veh(i,8+v-1)=6;
               veh(i,26+2*(v-1))=20.65;
               veh(i,27+2*(v-1))=0.26285;
            elseif y(v)>util(i,16) && y(v)<util(i,17)
               veh(i,8+v-1)=7;
               veh(i,26+2*(v-1))=26.6;
               veh(i,27+2*(v-1))=0.29577;
            elseif y(v)>util(i,17) && y(v)<util(i,18)
               veh(i,8+v-1)=8;
               veh(i,26+2*(v-1))=15.1;
               veh(i,27+2*(v-1))=0.16726;
            elseif y(v)>util(i,18) && y(v)<util(i,19)
               veh(i,8+v-1)=9;
               veh(i,26+2*(v-1))=15.18;
               veh(i,27+2*(v-1))=0.35221;
            end
         end
```

```
end

if veh(i,7)>0
    for v=1:veh(i,7)
        x(v)=rand;
        if x(v)<0.015625
            veh(i,21+v)=1;
        elseif x(v)>0.015625 && x(v)<0.0625
            veh(i,14+v-1)=2;
        elseif x(v)>0.0625 && x(v)<0.123958
            veh(i,14+v-1)=3;
        elseif x(v)>0.123958 && x(v)<0.18333
            veh(i,14+v-1)=4;
        elseif x(v)>0.18333 && x(v)<0.240625
            veh(i,14+v-1)=5;
        elseif x(v)>0.240625 && x(v)<0.295833
            veh(i,14+v-1)=6;
        elseif x(v)>0.295833 && x(v)<0.3489
            veh(i,14+v-1)=7;
        elseif x(v)>0.3489 && x(v)<0.4
            veh(i,14+v-1)=8;
        elseif x(v)>0.4 && x(v)<0.4489
            veh(i,14+v-1)=9;
        elseif x(v)>0.4489 && x(v)<0.49583
            veh(i,14+v-1)=10;
        elseif x(v)>0.49583 && x(v)<0.540625
            veh(i,14+v-1)=11;
        elseif x(v)>0.540625 && x(v)<0.5833
            veh(i,14+v-1)=12;
        elseif x(v)>0.5833 && x(v)<0.623958
            veh(i,14+v-1)=13;
        elseif x(v)>0.623958 && x(v)<0.6625
            veh(i,14+v-1)=14;
        elseif x(v)>0.6625 && x(v)<0.698958
            veh(i,14+v-1)=15;
        elseif x(v)>0.698958 && x(v)<0.733
            veh(i,14+v-1)=16;
        elseif x(v)>0.7333 && x(v)<0.765625
            veh(i,14+v-1)=17;
        elseif x(v)>0.765625 && x(v)<0.795833
            veh(i,14+v-1)=18;
        elseif x(v)>0.795833 && x(v)<0.823958
            veh(i,14+v-1)=19;
        elseif x(v)>0.823958 && x(v)<0.85
            veh(i,14+v-1)=20;
        elseif x(v)>0.85 && x(v)<0.8739
```

```
                veh(i,14+v-1)=21;
              elseif x(v)>0.8739 && x(v)<0.8958
                veh(i,14+v-1)=22;
              elseif x(v)>0.8958 && x(v)<0.915625
                 veh(i,14+v-1)=23;
              elseif x(v)>0.915625 && x(v)<0.933
                 veh(i,14+v-1)=24;
              elseif x(v)>0.9333 && x(v)<0.94895
                 veh(i,14+v-1)=25;
              elseif x(v)>0.94895 && x(v)<0.9625
                 veh(i,14+v-1)=26;
              elseif x(v)>0.9625 && x(v)<0.97395
                 veh(i,14+v-1)=27;
              elseif x(v)>0.97395 && x(v)<0.98333
                 veh(i,14+v-1)=28;
              elseif x(v)>0.98333 && x(v)<0.990625
                 veh(i,14+v-1)=29;
              elseif x(v)>0.990625 && x(v)<0.9958
                 veh(i,14+v-1)=30;
              elseif x(v)>0.9958 && x(v)<0.9989
                 veh(i,14+v-1)=31;
              elseif x(v)>0.9989
                 veh(i,14+v-1)=32;
              end
          end
      end
end

hh=veh;
time=1;
[c,d]=size(hh);
   temp=zeros(c,9);
   utilt=zeros(c,28);
   utility=zeros(c,30);

  for j=1:time
     for i=1:c
        temp(i,1)=exp(-1.831+ 0.25075*hh(i,4)+2.25*(hh(i,5)/10000000));%acquire
        temp(i,2)=exp(-3.7824+ 0.4077*hh(i,7)+2.25*(hh(i,5)/10000000));%dispose
        temp(i,3)=exp(-0.0955645*max(hh(i,14:19)));%do nothing

        temp(i,4)=sum(temp(i,1:3));
        temp(i,5)=temp(i,1)/temp(i,4);
        temp(i,6)=(temp(i,1)+temp(i,2))/temp(i,4);
        temp(i,7)=(temp(i,1)+temp(i,2)+temp(i,3))/temp(i,4);
```

```
    end

 for i=1:c
    if hh(i,2)>0
    x=rand;
    if x<temp(i,5)%vehicle bought
      utilt(i,1)=              exp(-2.21-2.717*(1.9)-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-
0.54216*hh(i,6)-0.668282*hh(i,7));
       utilt(i,2)=             exp(-2.54-2.717*(1.5)-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-
0.668282*hh(i,7));
       utilt(i,3)=              exp(1.05-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-2.717*(3.1)-
0.668282*hh(i,7));
       utilt(i,4)=            exp(2.28-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-2.717*(3.45)-
0.668282*hh(i,7));
       utilt(i,5)=             exp(-2.44-2.717*(1.7)-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-
0.668282*hh(i,7));
       utilt(i,6)=      exp(0.97-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-0.668282*hh(i,7)-
2.717*(2.5)+0.4355414*hh(i,6)-1.6902*hh(i,41));
       utilt(i,7)=                       exp(2.29-2.717*(3.3)+0.4520031*hh(i,41)+0.7990552*hh(i,42)-
2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-1.134284*hh(i,7)+0.81177*hh(i,23));
       utilt(i,8)=             exp(-0.24-2.717*(2.8)-2.35*(hh(i,5)/(hh(i,2)*100000))+0.04463*hh(i,3)-
0.49174*hh(i,7)+1.184962*hh(i,24)+1.87863*hh(i,41));
       utilt(i,9)=           exp(-0.71-2.35*(hh(i,5)/(hh(i,2)*100000))-2.717*(2.05)+0.04463*hh(i,3)-
0.668282*hh(i,7));
       utilt(i,10)= exp(-2.717*(2.9));
       utilt(i,11)=sum(utilt(i,1:10));
              % calculating the cummulative probabilites
       utilt(i,12)=utilt(i,1)/utilt(i,11);
       utilt(i,13)=(utilt(i,2)+utilt(i,1))/utilt(i,11);
       utilt(i,14)=(utilt(i,2)+utilt(i,1)+utilt(i,3))/utilt(i,11);
       utilt(i,15)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4))/utilt(i,11);
       utilt(i,16)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5))/utilt(i,11);
       utilt(i,17)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5)+utilt(i,6))/utilt(i,11);
       utilt(i,18)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5)+utilt(i,6)+utilt(i,7))/utilt(i,11);

utilt(i,19)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5)+utilt(i,6)+utilt(i,7)+utilt(i,8))/utilt(i,1
1);

utilt(i,20)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5)+utilt(i,6)+utilt(i,7)+utilt(i,8)+utilt(i,9)
)/utilt(i,11);

utilt(i,21)=(utilt(i,2)+utilt(i,1)+utilt(i,3)+utilt(i,4)+utilt(i,5)+utilt(i,6)+utilt(i,7)+utilt(i,8)+utilt(i,9)
+utilt(i,10))/utilt(i,11);
       y=rand;
              % 5 vehicle households #, class of vehicles updating
       if hh(i,7)==5 % 5 vehicle households
```

```
    hh(i,7)=hh(i,7)+1; % updating age of vehicle every year
    hh(i,14:19)=hh(i,14:19)+1;% updating age of vehicle every year

if y<utilt(i,12)
  hh(i,25)=1;
  hh(i,13)=6;
  hh(i,36)=29;
  hh(i,37)=0.19;
  elseif y>utilt(i,12) && y< utilt(i,13)
  hh(i,25)=2;
  hh(i,13)=7;
  hh(i,36)=31;
  hh(i,37)=0.15;
  elseif y>utilt(i,13) && y< utilt(i,14)
  hh(i,25)=3;
  hh(i,13)=2;
  hh(i,36)=22;
  hh(i,37)=0.31;
  elseif y>utilt(i,14) && y< utilt(i,15)
  hh(i,25)=4;
  hh(i,13)=3;
  hh(i,36)=22;
  hh(i,37)=0.48;
  elseif y>utilt(i,15) && y< utilt(i,16)
  hh(i,25)=5;
  hh(i,13)=7;
  hh(i,36)=36;
  hh(i,37)=0.17;
  elseif y>utilt(i,16) && y< utilt(i,17)
  hh(i,25)=6;
  hh(i,13)=4; %substituing midsize vehicle class for a HEV purchase
  hh(i,36)=46;
  hh(i,37)=0.25;
  elseif y>utilt(i,17) && y< utilt(i,18)
  hh(i,25)=7;
  hh(i,13)=4;%substituing midsize vehicle class for a PHEV purchase
  hh(i,36)=45;
  hh(i,37)=0.33;
  elseif y>utilt(i,18) && y< utilt(i,19)
  hh(i,25)=8;
  hh(i,13)=1;
  hh(i,36)=18.08;
  hh(i,37)=0.26932;
  elseif y>utilt(i,19) && y< utilt(i,20)
  hh(i,25)=9;
```

```
            hh(i,13)=8;
            hh(i,36)=23;
            hh(i,37)=0.205;
            elseif y>utilt(i,20) && y< utilt(i,21)
            hh(i,25)=10;
            hh(i,13)=5;
            hh(i,36)=15;
            hh(i,37)=0.29;
           end
% 4 vehicle households #, class of vehicles updating
elseif hh(i,7)==4 % 4 vehicle households
      hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
    hh(i,14:18)=hh(i,14:18)+1;

           if y<utilt(i,12)
            hh(i,25)=1;
            hh(i,12)=6;
            hh(i,34)=29;
            hh(i,35)=0.19;
            elseif y>utilt(i,12) && y< utilt(i,13)
            hh(i,25)=2;
            hh(i,12)=7;
            hh(i,34)=31;
            hh(i,35)=0.15;
            elseif y>utilt(i,13) && y< utilt(i,14)
            hh(i,25)=3;
            hh(i,12)=2;
            hh(i,34)=22;
            hh(i,35)=0.31;
            elseif y>utilt(i,14) && y< utilt(i,15)
            hh(i,25)=4;
            hh(i,12)=3;
            hh(i,34)=22;
            hh(i,35)=0.48;
            elseif y>utilt(i,15) && y< utilt(i,16)
            hh(i,25)=5;
            hh(i,12)=7;
            hh(i,34)=36;
            hh(i,35)=0.17;
            elseif y>utilt(i,16) && y< utilt(i,17)
            hh(i,25)=6;
            hh(i,12)=4;%substituing midsize vehicle class for a HEV purchase
            hh(i,34)=46;
            hh(i,35)=0.25;
            elseif y>utilt(i,17) && y< utilt(i,18)
            hh(i,25)=7;
```

```
            hh(i,12)=4;
            hh(i,34)=45;
            hh(i,35)=0.33;
            elseif y>utilt(i,18) && y< utilt(i,19)
            hh(i,25)=8;
            hh(i,12)=1;
            hh(i,34)=18.08;
            hh(i,35)=0.26932;
            elseif y>utilt(i,19) && y< utilt(i,20)
            hh(i,25)=9;
            hh(i,12)=8;
            hh(i,34)=23;
            hh(i,35)=0.205;
            elseif y>utilt(i,20) && y< utilt(i,21)
            hh(i,25)=10;
            hh(i,12)=5;
            hh(i,34)=15;
            hh(i,35)=0.29;
           end

    % three vehicle households #, class of vehicles updating
elseif hh(i,7)==3 % 3 vehicle households
   hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
   hh(i,14:17)=hh(i,14:17)+1;

   if y<utilt(i,12)
      hh(i,25)=1;
      hh(i,11)=6;
      hh(i,32)=29;
      hh(i,33)=0.19;
      elseif y>utilt(i,12) && y< utilt(i,13)
      hh(i,25)=2;
      hh(i,11)=7;
      hh(i,32)=31;
      hh(i,33)=0.15;
      elseif y>utilt(i,13) && y< utilt(i,14)
      hh(i,25)=3;
      hh(i,11)=2;
      hh(i,32)=22;
      hh(i,33)=0.31;
      elseif y>utilt(i,14) && y< utilt(i,15)
      hh(i,25)=4;
      hh(i,11)=3;
      hh(i,32)=22;
      hh(i,33)=0.48;
       elseif y>utilt(i,15) && y< utilt(i,16)
```

```
        hh(i,25)=5;
        hh(i,11)=7;
        hh(i,32)=36;
        hh(i,33)=0.17;
        elseif y>utilt(i,16) && y< utilt(i,17)
        hh(i,25)=6;
        hh(i,11)=4;%substituing midsize vehicle class for a HEV purchase
        hh(i,32)=46;
        hh(i,33)=0.25;
        elseif y>utilt(i,17) && y< utilt(i,18)
        hh(i,25)=7;
        hh(i,11)=4;
        hh(i,32)=45;
        hh(i,33)=0.33;
        elseif y>utilt(i,18) && y< utilt(i,19)
        hh(i,25)=8;
        hh(i,11)=1;
        hh(i,32)=18.08;
        hh(i,33)=0.26932;
        elseif y>utilt(i,19) && y< utilt(i,20)
        hh(i,25)=9;
        hh(i,11)=8;
        hh(i,32)=23;
        hh(i,33)=0.205;
        elseif y>utilt(i,20) && y< utilt(i,21)
        hh(i,25)=10;
        hh(i,11)=5;
        hh(i,32)=15;
        hh(i,33)=0.29;
     end


% two vehicle households #, class of vehicles updating
 elseif hh(i,7)==2 % 2 vehicle households
   hh(i,7)=hh(i,7)+1;
   hh(i,14:16)=hh(i,14:16)+1;% updating age of vehicle every year

   if y<utilt(i,12)
      hh(i,25)=1;
      hh(i,10)=6;
      hh(i,30)=29;
      hh(i,31)=0.19;
      elseif y>utilt(i,12) && y< utilt(i,13)
      hh(i,25)=2;
      hh(i,10)=7;
      hh(i,30)=31;
```

```
      hh(i,31)=0.15;
      elseif y>utilt(i,13) && y< utilt(i,14)
      hh(i,25)=3;
      hh(i,10)=2;
      hh(i,30)=22;
      hh(i,31)=0.31;
      elseif y>utilt(i,14) && y< utilt(i,15)
      hh(i,25)=4;
      hh(i,10)=3;
      hh(i,30)=22;
      hh(i,31)=0.48;
      elseif y>utilt(i,15) && y< utilt(i,16)
      hh(i,25)=5;
      hh(i,10)=7;
      hh(i,30)=36;
      hh(i,31)=0.17;
      elseif y>utilt(i,16) && y< utilt(i,17)
      hh(i,25)=6;
      hh(i,10)=4;%substituing midsize vehicle class for a HEV purchase
      hh(i,30)=46;
      hh(i,31)=0.25;
      elseif y>utilt(i,17) && y< utilt(i,18)
      hh(i,25)=7;
      hh(i,10)=4;
      hh(i,30)=45;
      hh(i,31)=0.33;
      elseif y>utilt(i,18) && y< utilt(i,19)
      hh(i,25)=8;
      hh(i,10)=1;
      hh(i,30)=18.08;
      hh(i,31)=0.26932;
      elseif y>utilt(i,19) && y< utilt(i,20)
      hh(i,25)=9;
      hh(i,10)=8;
      hh(i,30)=23;
      hh(i,31)=0.205;
      elseif y>utilt(i,20) && y< utilt(i,21)
      hh(i,25)=10;
     hh(i,10)=5;
     hh(i,30)=15;
       hh(i,31)=0.29;
  end


% one vehicle households #, class of vehicles updating
    elseif hh(i,7)==1 % 1 vehicle households
```

```
   hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
 hh(i,14:15)=hh(i,14:15)+1;
 if y<utilt(i,12)
   hh(i,25)=1;
  hh(i,9)=6;
  hh(i,28)=29;
  hh(i,29)=0.19;
 elseif y>utilt(i,12) && y< utilt(i,13)
    hh(i,25)=2;
  hh(i,9)=7;
  hh(i,28)=31;
  hh(i,29)=0.15;

elseif y>utilt(i,13) && y< utilt(i,14)
  hh(i,25)=3;
  hh(i,9)=2;
  hh(i,28)=22;
  hh(i,29)=0.31;
 elseif y>utilt(i,14) && y< utilt(i,15)
    hh(i,25)=4;
  hh(i,9)=3;
  hh(i,28)=22;
  hh(i,29)=0.48;

  elseif y>utilt(i,15) && y< utilt(i,16)
  hh(i,25)=5;
  hh(i,9)=7;
  hh(i,28)=36;
  hh(i,29)=0.17;
  elseif y>utilt(i,16) && y< utilt(i,17)
  hh(i,25)=6;
  hh(i,9)=4;%substituing midsize vehicle class for a HEV purchase
  hh(i,28)=46;
  hh(i,29)=0.25;
  elseif y>utilt(i,17) && y< utilt(i,18)
  hh(i,25)=7;
  hh(i,9)=4;
  hh(i,28)=45;
  hh(i,29)=0.33;
  elseif y>utilt(i,18) && y< utilt(i,19)
  hh(i,25)=8;
  hh(i,9)=1;
  hh(i,28)=18.08;
  hh(i,29)=0.26932;
  elseif y>utilt(i,19) && y< utilt(i,20)
  hh(i,25)=9;
```

```
  hh(i,9)=8;
  hh(i,28)=23;
  hh(i,29)=0.205;
  elseif y>utilt(i,20) && y< utilt(i,21)
  hh(i,25)=10;
  hh(i,9)=5;
  hh(i,28)=15;
  hh(i,29)=0.29;
end




 elseif hh(i,7)==0 % zero vehicle households
hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
if y<utilt(i,12)
    hh(i,25)=1;
hh(i,8)=6;
hh(i,26)=29;
hh(i,27)=0.19;

hh(i,14)=hh(i,14)+1;

elseif y>utilt(i,12) && y< utilt(i,13)

    hh(i,25)=2;
    hh(i,8)=7;
    hh(i,26)=31;
    hh(i,27)=0.15;

    hh(i,14)=hh(i,14)+1;
elseif y>utilt(i,13) && y< utilt(i,14)
    hh(i,25)=3;
    hh(i,8)=2;
    hh(i,26)=22;
    hh(i,27)=0.31;

    hh(i,14)=hh(i,14)+1;
elseif y>utilt(i,14) && y< utilt(i,15)
    hh(i,25)=4;
     hh(i,8)=3;
     hh(i,26)=22;
     hh(i,27)=0.48;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,15) && y< utilt(i,16)
```

```
    hh(i,25)=5;
     hh(i,8)=7;
     hh(i,26)=36;
    hh(i,27)=0.17;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,16) && y< utilt(i,17)
    hh(i,25)=6;
    hh(i,8)=4;%substituing midsize vehicle class for a HEV purchase
    hh(i,26)=46;
    hh(i,27)=0.25;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,17) && y< utilt(i,18)
    hh(i,25)=7;
    hh(i,8)=4;
    hh(i,26)=45;
    hh(i,27)=0.33;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,18) && y< utilt(i,19)
    hh(i,25)=8;
    hh(i,8)=1;
    hh(i,26)=18.08;
    hh(i,27)=0.26932;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,19) && y< utilt(i,20)
    hh(i,25)=9;
    hh(i,8)=8;
    hh(i,26)=23;
    hh(i,27)=0.205;

    hh(i,14)=hh(i,14)+1;
 elseif y>utilt(i,20) && y< utilt(i,21)
    hh(i,25)=10;
    hh(i,8)=5;
    hh(i,26)=15;
    hh(i,27)=0.29;

    hh(i,14)=hh(i,14)+1;

end
```

```
        end



   %% vehicle disposed




     elseif x>temp(i,5) && x<temp(i,6)%vehicle disposed


            if hh(i,7)==1 % 1 vehicle households
                hh(i,40)=hh(i,8);% updating disposed vehicle class
                hh(i,8)=0;
                hh(i,14)=0;

                hh(i,26)=0;
                hh(i,27)=0;
                 hh(i,7)=0;

            elseif hh(i,7)==2 % 2 vehicle households
                %first vehicle
                if hh(i,8)==1 % cuv
                    utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

                elseif hh(i,8)==2 % large
                    utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

                elseif hh(i,8)==3 % luxury
                    utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

                elseif hh(i,8)==4 % midsize
                    utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

                elseif hh(i,8)==5 % truck
                    utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);
```

```
        elseif hh(i,8)==6 % compact
          utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==7 % subcompact
          utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==8 % suv
          utility(i,1)=-
8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==9 % van
          utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27));
        end

         % second vehicle
        if hh(i,9)==1 % cuv
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==2 % large
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==3 % luxury
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==4 % midsize
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,9)==5 % truck
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==6 % compact
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==7 % subcompact
          utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);
```

```
            elseif hh(i,9)==8 % suv
               utility(i,2)=-
8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,9)==9 % van
               utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29));
            end


            if utility(i,2)>utility(i,1)
               hh(i,40)=hh(i,8);% updating disposed vehicle class
               hh(i,8)=hh(i,9); % move second vehicle to first vehicle
               hh(i,14)=hh(i,15);     %age of vehicle     and then update other vehicle details
               hh(i,26)=hh(i,28);
               hh(i,27)=hh(i,29);
               hh(i,28)=0;
               hh(i,29)=0;
               hh(i,9)=0;
               hh(i,15)=0;
            else
               hh(i,40)=hh(i,9);% updating disposed vehicle class
               hh(i,9)=0;
               hh(i,15)=0;
               hh(i,28)=0;
               hh(i,29)=0;
            end
            hh(i,14)=hh(i,14)+1;
            hh(i,7)=hh(i,7)-1;


         elseif hh(i,7)==3 % 3 vehicle households
            %first vehicle
            if hh(i,8)==1 % cuv
               utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==2 % large
               utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==3 % luxury
               utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==4 % midsize
```

```
                utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

            elseif hh(i,8)==5 % truck
                utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==6 % compact
                utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==7 % subcompact
                utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==8 % suv
                utility(i,1)=-
8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,8)==9 % van
                utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27));
            end

              % second vehicle
            if hh(i,9)==1 % cuv
                utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,9)==2 % large
                utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,9)==3 % luxury
                utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,9)==4 % midsize
                utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

            elseif hh(i,9)==5 % truck
                utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,9)==6 % compact
```

```
        utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,9)==7 % subcompact
        utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,9)==8 % suv
        utility(i,2)=-
8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,9)==9 % van
        utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29));
      end
       % third vehicle
      if hh(i,10)==1 % cuv
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==2 % large
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==3 % luxury
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==4 % midsize
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

      elseif hh(i,10)==5 % truck
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==6 % compact
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==7 % subcompact
        utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,10)==8 % suv
```

```
utility(i,3)=-
8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

    elseif hh(i,10)==9 % van
      utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31));
    end
    if utility(i,1)<utility(i,2) && utility(i,1)<utility(i,3)
      hh(i,40)=hh(i,8);% updating disposed vehicle class
      hh(i,8)=hh(i,10); % move third vehicle to first vehicle and then update other
vehicle details
       hh(i,14)=hh(i,16);
      hh(i,10)=0;
      hh(i,16)=0;
      hh(i,26)=hh(i,30);
      hh(i,27)=hh(i,31);
      hh(i,30)=0;
      hh(i,31)=0;
    elseif utility(i,1)>utility(i,2) && utility(i,2)<utility(i,3)
        hh(i,40)=hh(i,9);% updating disposed vehicle class
        hh(i,9)=hh(i,10);
        hh(i,15)=hh(i,16);
        hh(i,10)=0; % move third vehicle to second vehicle zero and then update other
vehicle details
        hh(i,16)=0;
        hh(i,28)=hh(i,30);
        hh(i,29)=hh(i,31);
        hh(i,30:31)=0;

    elseif utility(i,3)<utility(i,2) && utility(i,1)>utility(i,3)
        hh(i,40)=hh(i,10);% updating disposed vehicle class
        hh(i,9)=hh(i,10); % make third zero and then update other vehicle details

        hh(i,10)=0; % make third vehicle zero
        hh(i,16)=0;

        hh(i,30:31)=0;

       end
      hh(i,7)=hh(i,7)-1; % reducing number of vehicles in household
      hh(i,14:15)=hh(i,14:15)+1;

  elseif hh(i,7)==4 % 4 vehicle households
    %first vehicle
    if hh(i,8)==1 % cuv
```

```
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==2 % large
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==3 % luxury
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==4 % midsize
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

      elseif hh(i,8)==5 % truck
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==6 % compact
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==7 % subcompact
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==8 % suv
        utility(i,1)=-
8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,8)==9 % van
        utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27));
      end

       % second vehicle
      if hh(i,9)==1 % cuv
        utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,9)==2 % large
        utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

      elseif hh(i,9)==3 % luxury
```

```
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==4 % midsize
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,9)==5 % truck
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==6 % compact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==7 % subcompact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==8 % suv
            utility(i,2)=-
8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==9 % van
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29));
        end
         % third vehicle
        if hh(i,10)==1 % cuv
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==2 % large
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==3 % luxury
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==4 % midsize
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,10)==5 % truck
```

```
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==6 % compact
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==7 % subcompact
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==8 % suv
            utility(i,3)=-
8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==9 % van
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31));
          end
           % fourth vehicle
          if hh(i,11)==1 % cuv
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==2 % large
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==3 % luxury
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==4 % midsize
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

          elseif hh(i,11)==5 % truck
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==6 % compact
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==7 % subcompact
```

```
          utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==8 % suv
          utility(i,4)=-
8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==9 % van
          utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33));
        end
          if utility(i,1)<utility(i,2) && utility(i,1)<utility(i,3)  && utility(i,1)<utility(i,4)
            hh(i,40)=hh(i,8);% updating disposed vehicle class
            hh(i,8)=hh(i,11); % move fourth vehicle to first vehicle
            hh(i,14)=hh(i,17);
            hh(i,11)=0; % make fourth vehicle zero and then update other vehicle details
            hh(i,17)=0;
            hh(i,26)=hh(i,32);
            hh(i,27)=hh(i,33);
            hh(i,32)=0;
            hh(i,33)=0;
          elseif utility(i,4)<utility(i,2) && utility(i,4)<utility(i,3)  && utility(i,1)>utility(i,4)
              hh(i,40)=hh(i,11);% updating disposed vehicle class
            hh(i,11)=0; % make fourth vehicle zero and then update other vehicle details
            hh(i,17)=0;
             hh(i,32)=0;
            hh(i,33)=0;

          elseif utility(i,3)<utility(i,2) && utility(i,1)>utility(i,3)  && utility(i,3)<utility(i,4)
              hh(i,40)=hh(i,10);% updating disposed vehicle class
            hh(i,10)=hh(i,11); % move fourth to third vehicle and then update other vehicle
details
            hh(i,16)=hh(i,17);
            hh(i,30)=hh(i,32);
            hh(i,31)=hh(i,33);
            hh(i,11)=0; % make fourth vehicle zero
            hh(i,17)=0;
            hh(i,32)=0;
            hh(i,33)=0;
          elseif utility(i,1)>utility(i,2) && utility(i,2)<utility(i,3)  && utility(i,2)<utility(i,4)
              hh(i,40)=hh(i,9);% updating disposed vehicle class
            hh(i,9)=hh(i,11); % move fourth to second vehicle and then update other vehicle
details
            hh(i,15)=hh(i,17);
            hh(i,28)=hh(i,32);
            hh(i,29)=hh(i,33);
```

```
            hh(i,11)=0; % make fourth vehicle zero
            hh(i,17)=0;
            hh(i,32)=0;
            hh(i,33)=0;
              end

           hh(i,7)=hh(i,7)-1;   % reducing number of vehicles in household
           hh(i,14:16)=hh(i,14:16)+1;




      elseif hh(i,7)==5 % 5 vehicle households

         %first vehicle
         if hh(i,8)==1 % cuv
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==2 % large
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==3 % luxury
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==4 % midsize
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

         elseif hh(i,8)==5 % truck
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==6 % compact
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==7 % subcompact
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==8 % suv
```

```
            utility(i,1)=-
8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,8)==9 % van
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27));
         end

          % second vehicle
         if hh(i,9)==1 % cuv
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==2 % large
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==3 % luxury
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==4 % midsize
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

         elseif hh(i,9)==5 % truck
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==6 % compact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==7 % subcompact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==8 % suv
            utility(i,2)=-
8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

         elseif hh(i,9)==9 % van
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29));
         end
          % third vehicle
```

```
            if hh(i,10)==1 % cuv
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==2 % large
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==3 % luxury
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==4 % midsize
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

            elseif hh(i,10)==5 % truck
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==6 % compact
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==7 % subcompact
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==8 % suv
               utility(i,3)=-
8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,10)==9 % van
               utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31));
            end
             % fourth vehicle
            if hh(i,11)==1 % cuv
               utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,11)==2 % large
               utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,11)==3 % luxury
```

```
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==4 % midsize
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,11)==5 % truck
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==6 % compact
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==7 % subcompact
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==8 % suv
            utility(i,4)=-
8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,11)==9 % van
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33));
        end
         % fifth vehicle
        if hh(i,12)==1 % cuv
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==2 % large
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==3 % luxury
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==4 % midsize
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,12)==5 % truck
```

```
                utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,12)==6 % compact
                utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,12)==7 % subcompact
                utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,12)==8 % suv
                utility(i,5)=-
8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,12)==9 % van
                utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35));
            end
                if utility(i,1)<utility(i,2) && utility(i,1)<utility(i,3)  && utility(i,1)<utility(i,4)
&& utility(i,1)<utility(i,5)
                    hh(i,40)=hh(i,8);% updating disposed vehicle class
                   hh(i,8)=hh(i,12); % move fifth vehicle to first vehicle and then update other
vehicle details
                   hh(i,14)=hh(i,18);
                   hh(i,26)=hh(i,34);
                   hh(i,27)=hh(i,35);
                   hh(i,12)=0; % make fifth vehicle zero
                   hh(i,18)=0;
                   hh(i,34)=0;
                   hh(i,35)=0;
                elseif utility(i,5)<utility(i,2) && utility(i,5)<utility(i,3)  && utility(i,5)<utility(i,4)
&& utility(i,1)>utility(i,5)
                    hh(i,40)=hh(i,12);% updating disposed vehicle class
                   hh(i,12)=0; % make fifth vehicle zero and then update other vehicle details

                   hh(i,18)=0;
                   hh(i,34)=0;
                   hh(i,35)=0;

                elseif utility(i,3)<utility(i,2) && utility(i,1)>utility(i,3)  && utility(i,3)<utility(i,4)
&& utility(i,3)<utility(i,5)
                    hh(i,40)=hh(i,10);% updating disposed vehicle class
                   hh(i,10)=hh(i,12); % move fifth to third vehicle and then update other vehicle
details
                   hh(i,16)=hh(i,18);
```

```
                  hh(i,30)=hh(i,34);
                  hh(i,31)=hh(i,35);
                  hh(i,12)=0; % make fifth vehicle zero
                  hh(i,18)=0;
                  hh(i,34)=0;
                  hh(i,35)=0;
                elseif utility(i,1)>utility(i,2) && utility(i,2)<utility(i,3)  && utility(i,2)<utility(i,4)
&& utility(i,2)<utility(i,5)
                   hh(i,40)=hh(i,9);% updating disposed vehicle class
                  hh(i,9)=hh(i,12); % move fifth to second vehicle and then update other vehicle
details
                  hh(i,15)=hh(i,18);
                  hh(i,28)=hh(i,34);
                  hh(i,29)=hh(i,35);
                  hh(i,12)=0; % make fifth vehicle zero
                  hh(i,18)=0;
                  hh(i,34)=0;
                  hh(i,35)=0;
                elseif utility(i,4)<utility(i,2) && utility(i,4)<utility(i,3)  && utility(i,1)>utility(i,4)
&& utility(i,4)<utility(i,5)
                   hh(i,40)=hh(i,11);% updating disposed vehicle class
                  hh(i,11)=hh(i,12); % move fifth to fourth vehicle and then update other vehicle
details
                  hh(i,17)=hh(i,18);
                  hh(i,32)=hh(i,34);
                  hh(i,33)=hh(i,35);
                  hh(i,12)=0; % make fifth vehicle zero
                  hh(i,18)=0;
                  hh(i,34)=0;
                  hh(i,35)=0;
                  end
                hh(i,7)=hh(i,7)-1;      % reducing number of vehicles in household
                hh(i,14:17)=hh(i,14:17)+1;


        elseif hh(i,7)==6 % 6 vehicle households
           %first vehicle
           if hh(i,8)==1 % cuv
              utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

           elseif hh(i,8)==2 % large
              utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

           elseif hh(i,8)==3 % luxury
```

```
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==4 % midsize
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,8)==5 % truck
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==6 % compact
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==7 % subcompact
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==8 % suv
            utility(i,1)=-
8.513*(2.5/hh(i,26))+5.57*(hh(i,27))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,8)==9 % van
            utility(i,1)=-8.513*(2.5/hh(i,26))+5.57*(hh(i,27));
        end

         % second vehicle
        if hh(i,9)==1 % cuv
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==2 % large
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==3 % luxury
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==4 % midsize
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,9)==5 % truck
```

```
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==6 % compact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==7 % subcompact
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==8 % suv
            utility(i,2)=-
8.513*(2.5/hh(i,28))+5.57*(hh(i,29))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,9)==9 % van
            utility(i,2)=-8.513*(2.5/hh(i,28))+5.57*(hh(i,29));
        end
         % third vehicle
        if hh(i,10)==1 % cuv
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==2 % large
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==3 % luxury
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==4 % midsize
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,10)==5 % truck
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==6 % compact
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,10)==7 % subcompact
```

```
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==8 % suv
            utility(i,3)=-
8.513*(2.5/hh(i,30))+5.57*(hh(i,31))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,10)==9 % van
            utility(i,3)=-8.513*(2.5/hh(i,30))+5.57*(hh(i,31));
          end
           % fourth vehicle
          if hh(i,11)==1 % cuv
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==2 % large
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==3 % luxury
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==4 % midsize
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

          elseif hh(i,11)==5 % truck
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==6 % compact
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==7 % subcompact
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==8 % suv
            utility(i,4)=-
8.513*(2.5/hh(i,32))+5.57*(hh(i,33))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

          elseif hh(i,11)==9 % van
```

```
            utility(i,4)=-8.513*(2.5/hh(i,32))+5.57*(hh(i,33));
        end
         % fifth vehicle
        if hh(i,12)==1 % cuv
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==2 % large
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==3 % luxury
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==4 % midsize
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

        elseif hh(i,12)==5 % truck
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==6 % compact
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==7 % subcompact
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==8 % suv
            utility(i,5)=-
8.513*(2.5/hh(i,34))+5.57*(hh(i,35))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,12)==9 % van
            utility(i,5)=-8.513*(2.5/hh(i,34))+5.57*(hh(i,35));
        end
         % sixth vehicle
        if hh(i,13)==1 % cuv
            utility(i6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))-0.41484+0.0161*hh(i,22)-
0.28944*hh(i,2);

        elseif hh(i,13)==2 % large
```

```
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==3 % luxury
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))-1.1211+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==4 % midsize
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.0161*hh(i,22)-
0.28944*hh(i,2)+0.6656*hh(i,4)+0.1864*hh(i,23);

            elseif hh(i,13)==5 % truck
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==6 % compact
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==7 % subcompact
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==8 % suv
                utility(i,6)=-
8.513*(2.5/hh(i,36))+5.57*(hh(i,37))+0.8756*hh(i,39)+0.26323*hh(i,24)+0.0161*hh(i,22)-
0.28944*hh(i,2);

            elseif hh(i,13)==9 % van
                utility(i,6)=-8.513*(2.5/hh(i,36))+5.57*(hh(i,37));
            end

                  if utility(i,1)<utility(i,2) && utility(i,1)<utility(i,3)  && utility(i,1)<utility(i,4)
&& utility(i,1)<utility(i,5) && utility(i,1)<utility(i,6)
                    hh(i,40)=hh(i,8);  % updating disposed vehicle class
                    hh(i,8)=hh(i,13); % move sixth vehicle to first vehicle and then update other
vehicle details
                    hh(i,14)=hh(i,19);
                    hh(i,26)=hh(i,36);
                    hh(i,27)=hh(i,37);
                    hh(i,36)=0;
                    hh(i,37)=0;
                    hh(i,13)=0; % make sixth vehicle zero
                    hh(i,19)=0;
```

```
elseif utility(i,6)<utility(i,2) && utility(i,6)<utility(i,3)  && utility(i,6)<utility(i,4) && utility(i,6)<utility(i,5) && utility(i,1)>utility(i,6)
    hh(i,40)=hh(i,13); % updating disposed vehicle class
    hh(i,13)=0; % make sixth vehicle zero and then update other vehicle details
    hh(i,19)=0;


    hh(i,36)=0;
    hh(i,37)=0;
elseif utility(i,3)<utility(i,2) && utility(i,1)>utility(i,3)  && utility(i,3)<utility(i,4) && utility(i,3)<utility(i,5) && utility(i,3)<utility(i,6)
    hh(i,40)=hh(i,10);  % updating disposed vehicle class
    hh(i,10)=hh(i,13); % move sixth to third vehicle and then update other vehicle details
    hh(i,16)=hh(i,19);
    hh(i,30)=hh(i,36);
    hh(i,31)=hh(i,37);
    hh(i,36)=0;
    hh(i,37)=0;
    hh(i,19)=0; % make sixth vehicle zero
    hh(i,13)=0;
elseif utility(i,1)>utility(i,2) && utility(i,2)<utility(i,3)  && utility(i,2)<utility(i,4) && utility(i,2)<utility(i,5) && utility(i,2)<utility(i,6)
    hh(i,40)=hh(i,9); % updating disposed vehicle class
    hh(i,9)=hh(i,13); % move sixth to second vehicle and then update other vehicle details
    hh(i,15)=hh(i,19);
    hh(i,28)=hh(i,36);
    hh(i,29)=hh(i,37);
    hh(i,36)=0;
    hh(i,37)=0;
    hh(i,19)=0; % make sixth vehicle zero
    hh(i,13)=0;
elseif utility(i,4)<utility(i,2) && utility(i,4)<utility(i,3)  && utility(i,1)>utility(i,4) && utility(i,4)<utility(i,5) && utility(i,4)<utility(i,6)
    hh(i,40)=hh(i,11);  % updating disposed vehicle class
    hh(i,11)=hh(i,13); % move sixth to fourth vehicle and then update other vehicle details
    hh(i,17)=hh(i,19);
    hh(i,32)=hh(i,36);
    hh(i,33)=hh(i,37);
    hh(i,36)=0;
    hh(i,37)=0;
    hh(i,13)=0; % make sixth vehicle zero
    hh(i,19)=0;
```

```
                elseif utility(i,5)<utility(i,2) && utility(i,5)<utility(i,3)  && utility(i,5)<utility(i,4)
&& utility(i,1)>utility(i,5) && utility(i,5)<utility(i,6)
                 hh(i,40)=hh(i,12);  % updating disposed vehicle class
                 hh(i,12)=hh(i,13); % move sixth to fifth vehicle and then update other vehicle
details
                 hh(i,18)=hh(i,19);
                 hh(i,34)=hh(i,36);
                 hh(i,35)=hh(i,37);
                 hh(i,36)=0;
                 hh(i,37)=0;
                 hh(i,13)=0; % make sixth vehicle zero
                 hh(i,19)=0;
                end


               hh(i,7)=hh(i,7)-1;      % reducing number of vehicles in household
               hh(i,14:18)=hh(i,14:18)+1;
          end

    end
    end
 end

dlmwrite('C:\Documents and Settings\setup-
01\Desktop\test\TRENDalscenario\year1veh_synthetic_evolved.dat',hh);

  end
```

APPENDIX E: SPSS CODE FOR VEHICLE USAGE

```
COMPUTE VMT_1 = EXP(9.492+0.0193*V2+0.0575*V4+9.13*(V5/10000000)-0.0217
 *V14-6.4*(popdens_acre/100000)-0.1194*(1-V23)+RV.NORMAL(0,0.46269))  .
EXECUTE .
COMPUTE VMT_2 = EXP(9.492+0.0193*V2+0.0575*V4+9.13*(V5/10000000)-0.0217
 *V15-6.4*(popdens_acre/100000)-0.1194*(1-V23)+RV.NORMAL(0,0.46269))  .
EXECUTE .
COMPUTE VMT_3 = EXP(9.492+0.0193*V2+0.0575*V4+9.13*(V5/10000000)-0.0217
 *V16-6.4*(popdens_acre/100000)-0.1194*(1-V23)+RV.NORMAL(0,0.46269))  .
EXECUTE .
COMPUTE VMT_4 = EXP(9.492+0.0193*V2+0.0575*V4+9.13*(V5/10000000)-0.0217
 *V17-6.4*(popdens_acre/100000)-0.1194*(1-V23)+RV.NORMAL(0,0.46269))  .
EXECUTE .
COMPUTE VMT_5 = EXP(9.492+0.0193*V2+0.0575*V4+9.13*(V5/10000000)-0.0217
 *V18-6.4*(popdens_acre/100000)-0.1194*(1-V23)+RV.NORMAL(0,0.46269))  .
EXECUTE .

IF (V26 = 14.67) truck_1_1 = VMT_1*exp(-0.0229*17.04158+0.0014*V14) .
EXECUTE .

IF (V28 = 14.67) truck_1_2 = VMT_2*exp(-0.0229*17.04158+0.0014*V15) .
EXECUTE .

IF (V30 = 14.67) truck_1_3 = VMT_3*exp(-0.0229*17.04158+0.0014*V16) .
EXECUTE .

IF (V32 = 14.67) truck_1_4 = VMT_4*exp(-0.0229*17.04158+0.0014*V17) .
EXECUTE .

IF (V34 = 14.67) truck_1_5 = VMT_5*exp(-0.0229*17.04158+0.0014*V18) .
EXECUTE .
RECODE
  truck_1_1 truck_1_2 truck_1_3 truck_1_4 truck_1_5  (MISSING=0)  .
EXECUTE .
COMPUTE truck_1_sum = truck_1_1 + truck_1_2 + truck_1_3 + truck_1_4 + truck_1_5 .
EXECUTE .
IF (truck_1_sum > 0) truck_1_presence = 1 .
EXECUTE .
RECODE
  truck_1_presence  (MISSING=0)  .
EXECUTE .
```

```
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=truck_1_presence
  /truck_1_sum_sum = SUM(truck_1_sum).
FREQUENCIES
  VARIABLES=truck_1_presence
  /ORDER=  ANALYSIS .

IF (V26=15.00) truck_2_1 = VMT_1*exp(-0.0229*16.6667+0.0014*V14)  .
EXECUTE .

IF (V28=15.00) truck_2_2 = VMT_2*exp(-0.0229*16.6667+0.0014*V15)  .
EXECUTE .

IF (V30=15.00) truck_2_3 = VMT_3*exp(-0.0229*16.6667+0.0014*V16)  .
EXECUTE .

IF (V32=15.00) truck_2_4 = VMT_4*exp(-0.0229*16.6667+0.0014*V17)  .
EXECUTE .

IF (V34=15.00) truck_2_5 = VMT_5*exp(-0.0229*16.6667+0.0014*V18)  .
EXECUTE .
RECODE
  truck_2_1 truck_2_2 truck_2_3 truck_2_4 truck_2_5  (MISSING=0)  .
EXECUTE .
COMPUTE truck_2_sum = truck_2_1 + truck_2_2 + truck_2_3 + truck_2_4 + truck_2_5 .
EXECUTE .
IF (truck_2_sum > 0) truck_2_presence = 1 .
EXECUTE .
RECODE
  truck_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=truck_2_presence
  /truck_2_sum_sum = SUM(truck_2_sum).
FREQUENCIES
  VARIABLES=truck_2_presence
  /ORDER=  ANALYSIS .

IF (V26 = 26.60) subcompact_1_1 = VMT_1*exp(-0.0229*9.398496) .
EXECUTE .
```

```
IF (V28 = 26.60) subcompact_1_2 = VMT_2*exp(-0.0229*9.398496) .
EXECUTE .

IF (V30 = 26.60) subcompact_1_3 = VMT_3*exp(-0.0229*9.398496) .
EXECUTE .

IF (V32 = 26.60 ) subcompact_1_4 = VMT_4*exp(-0.0229*9.398496) .
EXECUTE .

IF (V34 = 26.60 ) subcompact_1_5 = VMT_5*exp(-0.0229*9.398496) .
EXECUTE .
RECODE
  subcompact_1_1  subcompact_1_2  subcompact_1_3  subcompact_1_4  subcompact_1_5
(MISSING=0)  .
EXECUTE .
COMPUTE subcompact_1_sum = subcompact_1_1 + subcompact_1_2 + subcompact_1_3 +
subcompact_1_4 + subcompact_1_5 .
EXECUTE .
IF (subcompact_1_sum > 0) subcompact_1_presence = 1 .
EXECUTE .
RECODE
  subcompact_1_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=subcompact_1_presence
  /subcompact_1_sum_sum = SUM(subcompact_1_sum).
FREQUENCIES
  VARIABLES=subcompact_1_presence
  /ORDER=  ANALYSIS .

IF (V26 = 31.00) subcompact_2_1 = VMT_1*exp(-0.0229*8.064516) .
EXECUTE .

IF (V28 = 31.00) subcompact_2_2 = VMT_2*exp(-0.0229*8.064516) .
EXECUTE .

IF (V30 = 31.00) subcompact_2_3 = VMT_3*exp(-0.0229*8.064516) .
EXECUTE .

IF (V32 = 31.00) subcompact_2_4 = VMT_4*exp(-0.0229*8.064516) .
EXECUTE .
```

```
IF (V34 = 31.00) subcompact_2_5 = VMT_5*exp(-0.0229*8.064516) .
EXECUTE .
RECODE
  subcompact_2_1   subcompact_2_2   subcompact_2_3   subcompact_2_4   subcompact_2_5
(MISSING=0)  .
EXECUTE .
COMPUTE subcompact_2_sum = subcompact_2_1 + subcompact_2_2 + subcompact_2_3 +
subcompact_2_4 + subcompact_2_5 .
EXECUTE .
IF (subcompact_2_sum > 0) subcompact_2_presence = 1 .
EXECUTE .
RECODE
  subcompact_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=subcompact_2_presence
  /subcompact_2_sum_sum = SUM(subcompact_2_sum).
FREQUENCIES
  VARIABLES=subcompact_2_presence
  /ORDER=  ANALYSIS .



IF (V26 = 20.65) compact_1_1 = VMT_1*exp(-0.0229*12.10654) .
EXECUTE .

IF (V28 = 20.65) compact_1_2 = VMT_2*exp(-0.0229*12.10654) .
EXECUTE .

IF (V30 = 20.65) compact_1_3 = VMT_3*exp(-0.0229*12.10654) .
EXECUTE .

IF (V32 = 20.65) compact_1_4 = VMT_4*exp(-0.0229*12.10654) .
EXECUTE .

IF (V34 = 20.65) compact_1_5 = VMT_5*exp(-0.0229*12.10654) .
EXECUTE .
RECODE
  compact_1_1 compact_1_2 compact_1_3 compact_1_4 compact_1_5  (MISSING=0)  .
EXECUTE .
```

```
COMPUTE compact_1_sum = compact_1_1 + compact_1_2 + compact_1_3 + compact_1_4 +
compact_1_5 .
EXECUTE .
IF (compact_1_sum > 0) compact_1_presence = 1 .
EXECUTE .
RECODE
  compact_1_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=compact_1_presence
  /compact_1_sum_sum = SUM(compact_1_sum).
FREQUENCIES
  VARIABLES=compact_1_presence
  /ORDER=  ANALYSIS .


IF (V26 = 29.00) compact_2_1 = VMT_1*exp(-0.0229*8.62069) .
EXECUTE .

IF (V28 = 29.00) compact_2_2 = VMT_2*exp(-0.0229*8.62069) .
EXECUTE .

IF (V30 = 29.00) compact_2_3 = VMT_3*exp(-0.0229*8.62069) .
EXECUTE .

IF (V32 = 29.00) compact_2_4 = VMT_4*exp(-0.0229*8.62069) .
EXECUTE .

IF (V34 = 29.00) compact_2_5 = VMT_5*exp(-0.0229*8.62069) .
EXECUTE .
RECODE
  compact_2_1 compact_2_2 compact_2_3 compact_2_4 compact_2_5  (MISSING=0)  .
EXECUTE .
COMPUTE compact_2_sum = compact_2_1 + compact_2_2 + compact_2_3 + compact_2_4 +
compact_2_5 .
EXECUTE .
IF (compact_2_sum > 0) compact_2_presence = 1 .
EXECUTE .
RECODE
  compact_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
```

```
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=compact_2_presence
  /compact_2_sum_sum = SUM(compact_2_sum).
FREQUENCIES
  VARIABLES=compact_2_presence
  /ORDER=  ANALYSIS .



IF (V26 = 15.10) suv_1_1 = VMT_1*exp(-0.01514*16.55629) .
EXECUTE .

IF (V28 = 15.10) suv_1_2 = VMT_2*exp(-0.01514*16.55629) .
EXECUTE .

IF (V30 = 15.10) suv_1_3 = VMT_3*exp(-0.01514*16.55629) .
EXECUTE .

IF (V32 = 15.10) suv_1_4 = VMT_4*exp(-0.01514*16.55629) .
EXECUTE .

IF (V34 = 15.10) suv_1_5 = VMT_5*exp(-0.01514*16.55629) .
EXECUTE .
RECODE
  suv_1_1 suv_1_2 suv_1_3 suv_1_4 suv_1_5  (MISSING=0)  .
EXECUTE .
COMPUTE suv_1_sum = suv_1_1 + suv_1_2 + suv_1_3 + suv_1_4 + suv_1_5 .
EXECUTE .
IF (suv_1_sum > 0) suv_1_presence = 1 .
EXECUTE .
RECODE
  suv_1_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=suv_1_presence
  /suv_1_sum_sum = SUM(suv_1_sum).
FREQUENCIES
  VARIABLES=suv_1_presence
  /ORDER=  ANALYSIS .
```

```
IF (V26 = 23.00) suv_2_1 = VMT_1*exp(-0.01514*10.86957) .
EXECUTE .

IF (V28 = 23.00) suv_2_2 = VMT_2*exp(-0.01514*10.86957) .
EXECUTE .

IF (V30 = 23.00) suv_2_3 = VMT_3*exp(-0.01514*10.86957) .
EXECUTE .

IF (V32 = 23.00) suv_2_4 = VMT_4*exp(-0.01514*10.86957) .
EXECUTE .

IF (V34 = 23.00) suv_2_5 = VMT_5*exp(-0.01514*10.86957) .
EXECUTE .
RECODE
  suv_2_1 suv_2_2 suv_2_3 suv_2_4 suv_2_5  (MISSING=0)  .
EXECUTE .
COMPUTE suv_2_sum = suv_2_1 + suv_2_2 + suv_2_3 + suv_2_4 + suv_2_5 .
EXECUTE .
IF (suv_2_sum > 0) suv_2_presence = 1 .
EXECUTE .
RECODE
  suv_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=suv_2_presence
  /suv_2_sum_sum = SUM(suv_2_sum).
FREQUENCIES
  VARIABLES=suv_2_presence
  /ORDER=  ANALYSIS .



IF (V26 = 18.61) lux_1_1 = VMT_1*exp(-0.0229*13.43364) .
EXECUTE .

IF (V28 = 18.61) lux_1_2 = VMT_2*exp(-0.0229*13.43364) .
EXECUTE .

IF (V30 = 18.61) lux_1_3 = VMT_3*exp(-0.0229*13.43364) .
EXECUTE .
```

```
IF (V32 = 18.61) lux_1_4 = VMT_4*exp(-0.0229*13.43364) .
EXECUTE .

IF (V34 = 18.61) lux_1_5 = VMT_5*exp(-0.0229*13.43364) .
EXECUTE .
RECODE
  lux_1_1 lux_1_2 lux_1_3 lux_1_4 lux_1_5  (MISSING=0)  .
EXECUTE .
COMPUTE lux_1_sum = lux_1_1 + lux_1_2 + lux_1_3 + lux_1_4 + lux_1_5 .
EXECUTE .
IF (lux_1_sum > 0) lux_1_presence = 1 .
EXECUTE .
RECODE
  lux_1_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=lux_1_presence
  /lux_1_sum_sum = SUM(lux_1_sum).
FREQUENCIES
  VARIABLES=lux_1_presence
  /ORDER=  ANALYSIS .


IF ( (V26=22.00 & V27=0.48) ) lux_2_1 = VMT_1*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V28=22.00 & V29=0.48)) lux_2_2 = VMT_2*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V30=22.00 & V31=0.48)) lux_2_3 = VMT_3*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V32=22.00 & V33=0.48)) lux_2_4 = VMT_4*exp(-0.0229*11.36364) .
EXECUTE .

IF ((V34=22.00 & V35=0.48)) lux_2_5 = VMT_5*exp(-0.0229*11.36364) .
EXECUTE .
RECODE
  lux_2_1 lux_2_2 lux_2_3 lux_2_4 lux_2_5  (MISSING=0)  .
EXECUTE .
COMPUTE lux_2_sum = lux_2_1 + lux_2_2 + lux_2_3 + lux_2_4 + lux_2_5 .
EXECUTE .
```

```
IF (lux_2_sum > 0) lux_2_presence = 1 .
EXECUTE .
RECODE
  lux_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=lux_2_presence
  /lux_2_sum_sum = SUM(lux_2_sum).
FREQUENCIES
  VARIABLES=lux_2_presence
  /ORDER=  ANALYSIS .



IF (V26 = 17.57 ) large_1_1 = VMT_1*exp(-0.0229*14.2288) .
EXECUTE .

IF (V28 = 17.57 ) large_1_2 = VMT_2*exp(-0.0229*14.2288) .
EXECUTE .

IF (V30 = 17.57) large_1_3 = VMT_3*exp(-0.0229*14.2288) .
EXECUTE .

IF (V32 = 17.57) large_1_4 = VMT_4*exp(-0.0229*14.2288) .
EXECUTE .

IF (V34 = 17.57) large_1_5 = VMT_5*exp(-0.0229*14.2288) .
EXECUTE .
RECODE
  large_1_1 large_1_2 large_1_3 large_1_4 large_1_5  (MISSING=0)  .
EXECUTE .
COMPUTE large_1_sum = large_1_1 + large_1_2 + large_1_3 + large_1_4 + large_1_5 .
EXECUTE .
IF (large_1_sum > 0) large_1_presence = 1 .
EXECUTE .
RECODE
  large_1_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=large_1_presence
```

```
  /large_1_sum_sum = SUM(large_1_sum).
FREQUENCIES
  VARIABLES=large_1_presence
  /ORDER=  ANALYSIS .



IF ( (V26=22.00 & V27=0.31)) large_2_1 = VMT_1*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V28=22.00 & V29=0.31)) large_2_2 = VMT_2*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V30=22.00 & V31=0.31)) large_2_3 = VMT_3*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V32=22.00 & V33=0.31)) large_2_4 = VMT_4*exp(-0.0229*11.36364) .
EXECUTE .

IF ( (V34=22.00 & V35=0.31)) large_2_5 = VMT_5*exp(-0.0229*11.36364) .
EXECUTE .
RECODE
  large_2_1 large_2_2 large_2_3 large_2_4 large_2_5  (MISSING=0)  .
EXECUTE .
COMPUTE large_2_sum = large_2_1 + large_2_2 + large_2_3 + large_2_4 + large_2_5 .
EXECUTE .
IF (large_2_sum > 0) large_2_presence = 1 .
EXECUTE .
RECODE
  large_2_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=large_2_presence
  /large_2_sum_sum = SUM(large_2_sum).
FREQUENCIES
  VARIABLES=large_2_presence
  /ORDER=  ANALYSIS .



IF (V26 = 18.08) cuv_1 = VMT_1*exp(-0.0229*13.82743) .
EXECUTE .
```

```
IF (V28 = 18.08) cuv_2 = VMT_2*exp(-0.0229*13.82743)  .
EXECUTE .

IF (V30 = 18.08) cuv_3 = VMT_3*exp(-0.0229*13.82743)  .
EXECUTE .

IF (V32 = 18.08 ) cuv_4 = VMT_4*exp(-0.0229*13.82743)  .
EXECUTE .

IF (V34 = 18.08) cuv_5 = VMT_5*exp(-0.0229*13.82743)  .
EXECUTE .
RECODE
  cuv_1 cuv_2 cuv_3 cuv_4 cuv_5  (MISSING=0)  .
EXECUTE .
COMPUTE cuv_sum = cuv_1 + cuv_2 + cuv_3 + cuv_4 + cuv_5 .
EXECUTE .
IF (cuv_sum > 0) cuv_presence = 1 .
EXECUTE .
RECODE
  cuv_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=cuv_presence
  /cuv_sum_sum = SUM(cuv_sum).
FREQUENCIES
  VARIABLES=cuv_presence
  /ORDER=  ANALYSIS .

IF (V26 = 19.00) midsize_1 = VMT_1*exp(-0.0229*13.15789) .
EXECUTE .

IF (V28 = 19.00) midsize_2 = VMT_2*exp(-0.0229*13.15789)  .
EXECUTE .

IF (V30 = 19.00) midsize_3 = VMT_3*exp(-0.0229*13.15789)  .
EXECUTE .

IF (V32 = 19.00) midsize_4 = VMT_4*exp(-0.0229*13.15789)  .
EXECUTE .

IF (V34 = 19.00) midsize_5 = VMT_5*exp(-0.0229*13.15789)  .
```

```
EXECUTE .
RECODE
  midsize_1 midsize_2 midsize_3 midsize_4 midsize_5  (MISSING=0)  .
EXECUTE .
COMPUTE midsize_sum = midsize_1 + midsize_2 + midsize_3 + midsize_4 + midsize_5 .
EXECUTE .
IF (midsize_sum > 0) midsize_presence = 1 .
EXECUTE .
RECODE
  midsize_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=midsize_presence
  /midsize_sum_sum = SUM(midsize_sum).
FREQUENCIES
  VARIABLES=midsize_presence
  /ORDER=  ANALYSIS .


IF (V26 = 15.18) van_1 = VMT_1*exp(-0.01465*16.46904) .
EXECUTE .

IF (V28 = 15.18) van_2 = VMT_2*exp(-0.01465*16.46904) .
EXECUTE .

IF (V30 = 15.18) van_3 = VMT_3*exp(-0.01465*16.46904) .
EXECUTE .

IF (V32 = 15.18) van_4 = VMT_4*exp(-0.01465*16.46904) .
EXECUTE .

IF (V34 = 15.18) van_5 = VMT_5*exp(-0.01465*16.46904) .
EXECUTE .
RECODE
  van_1 van_2 van_3 van_4 van_5  (MISSING=0)  .
EXECUTE .
COMPUTE van_sum = van_1 + van_2 + van_3 + van_4 + van_5 .
EXECUTE .
IF (van_sum > 0) van_presence = 1 .
EXECUTE .
RECODE
  van_presence  (MISSING=0)  .
```

```
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=van_presence
  /van_sum_sum = SUM(van_sum).
FREQUENCIES
  VARIABLES=van_presence
  /ORDER=  ANALYSIS .


IF (V26 = 46.00) hev_1 = VMT_1*exp(-0.0229*5.434783) .
EXECUTE .

IF (V28 = 46.00) hev_2 = VMT_2*exp(-0.0229*5.434783) .
EXECUTE .

IF (V30 = 46.00) hev_3 = VMT_3*exp(-0.0229*5.434783) .
EXECUTE .

IF (V32 = 46.00) hev_4 = VMT_4*exp(-0.0229*5.434783) .
EXECUTE .

IF (V34 = 46.00) hev_5 = VMT_5*exp(-0.0229*5.434783) .
EXECUTE .
RECODE
  hev_1 hev_2 hev_3 hev_4 hev_5  (MISSING=0)  .
EXECUTE .
COMPUTE hev_sum = hev_1 + hev_2 + hev_3 + hev_4 + hev_5 .
EXECUTE .
IF (hev_sum > 0) hev_presence = 1 .
EXECUTE .
RECODE
  hev_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=hev_presence
  /hev_sum_sum = SUM(hev_sum).
FREQUENCIES
  VARIABLES=hev_presence
  /ORDER=  ANALYSIS .
```

```
IF (V26 = 45.00) phev_1 = VMT_1*exp(-0.0229*3.902778) .
EXECUTE .

IF (V28 = 45.00) phev_2 = VMT_2*exp(-0.0229*3.902778) .
EXECUTE .

IF (V30 = 45.00) phev_3 = VMT_3*exp(-0.0229*3.902778) .
EXECUTE .

IF (V32 = 45.00) phev_4 = VMT_4*exp(-0.0229*3.902778) .
EXECUTE .

IF (V34 = 45.00) phev_5 = VMT_5*exp(-0.0229*3.902778) .
EXECUTE .
RECODE
  phev_1 phev_2 phev_3 phev_4 phev_5  (MISSING=0)  .
EXECUTE .
COMPUTE phev_sum = phev_1 + phev_2 + phev_3 + phev_4 + phev_5 .
EXECUTE .
IF (phev_sum > 0) phev_presence = 1 .
EXECUTE .
RECODE
  phev_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=phev_presence
  /phev_sum_sum = SUM(phev_sum).
FREQUENCIES
  VARIABLES=phev_presence
  /ORDER=  ANALYSIS .

IF (V26 = 36.00) smart_1 = VMT_1*exp(-0.0229*6.944) .
EXECUTE .

IF (V28 = 36.00) smart_2 = VMT_2*exp(-0.0229*6.944) .
EXECUTE .

IF (V30 = 36.00) smart_3 = VMT_3*exp(-0.0229*6.944) .
EXECUTE .

IF (V32 = 36.00) smart_4 = VMT_4*exp(-0.0229*6.944) .
EXECUTE .
```

```
IF (V34 = 36.00) smart_5 = VMT_5*exp(-0.0229*6.944) .
EXECUTE .
RECODE
  smart_1 smart_2 smart_3 smart_4 smart_5  (MISSING=0)  .
EXECUTE .
COMPUTE smart_sum = smart_1 + smart_2 + smart_3 + smart_4 + smart_5 .
EXECUTE .
IF (smart_sum > 0) smart_presence = 1 .
EXECUTE .
RECODE
  smart_presence  (MISSING=0)  .
EXECUTE .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=smart_presence
  /smart_sum_sum = SUM(smart_sum).
FREQUENCIES
  VARIABLES=smart_presence
  /ORDER=  ANALYSIS .
```