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16. Abstract

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The second part of this report relies on data from the U.S. Consumer Expenditure Survey (CEX) to estimate the welfare impacts of carbon taxes and household-level capping of emissions (with carbon-credit trading allowed). A translog utility framework was calibrated and then used to anticipate household expenditures across nine consumer goods categories, including vehicle usage and vehicle expenses. An input-output model was used to estimate the impact of carbon pricing on goods prices, and a vehicle choice model determined vehicle type preferences, along with each household's effective travel costs. Behaviors were predicted under two carbon tax scenarios ($50 per ton and $100 per ton of CO2-equivalents) and four cap-and-trade scenarios (10-ton and 15-ton cap per person per year with trading allowed at $50 per ton and $100 per ton carbon price). Carbon taxes were found to relatively regressive than a cap-and-trade setting (in terms of taxes paid per dollar of expenditure), but a tax-revenue redistribution can be used to offset this regressivity. In the absence of substitution opportunities (within each of the nine expenditure categories), these results represent highly conservative (worst-case) results, but they illuminate the behavioral response trends while providing a rigorous framework for future work.

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The Light-Duty-Vehicle Fleet's Evolution: Anticipating PHEV Adoption and Greenhouse Gas Emissions Across the U.S. Fleet

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ABSTRACT

The first part of this report relies on stated and revealed preference survey results across a sample of U.S. households to first ascertain vehicle acquisition, disposal, and use patterns, and then simulate these for a synthetic population over time. Results include predictions of future U.S. household-fleet composition, use, and greenhouse gas (GHG) emissions under nine different scenarios, including variations in fuel and plug-in-electric-vehicle (PHEV) prices, new-vehicle feebate policies, and land-use-density settings. This work highlights the impacts of various directions consumers may head with such vehicles. For example, twenty-five-year simulations at gas prices at $7 per gallon resulted in the second highest market share predictions (16.30%) for PHEVs, HEVs, and Smart Cars (combined) — and the greatest GHG-emissions reductions. The strciter feebate policy (pivot point at 30 mpg and fee or rebate rate of $400 per mpg) – coupled with gasoline at $5 per gallon – resulted in the highest market share (16.37%) for PHEVs, HEVs, and Smart Cars, but not as much GHG emissions reduction as the $7 gas price scenario. Excepting the low PHEV price and two feebate policy simulations, all other scenarios predicted a lower fleet VMT. While plug-in vehicles are now hitting the market, their adoption and widespread use will depend on thoughtful marketing, competitive pricing, government incentives, reliable driving-range reports, and adequate charging infrastructure.

The second part of this report relies on data from the U.S. Consumer Expenditure Survey (CEX) to estimate the welfare impacts of carbon taxes and household-level capping of emissions (with carbon-credit trading allowed). A translog utility framework was calibrated and then used to anticipate household expenditures across nine consumer goods categories, including vehicle usage and vehicle expenses. An input-output model was used to estimate the impact of carbon pricing on goods prices, and a vehicle choice model determined vehicle type preferences, along with each household's effective travel costs. Behaviors were predicted under two carbon tax scenarios ($50 per ton and $100 per ton of CO2-equivalents) and four cap-and-trade scenarios (10-ton and 15-ton cap per person per year with trading allowed at $50 per ton and $100 per ton carbon price). Carbon taxes were found to relatively regressive than a cap-and-trade setting (in terms of taxes paid per dollar of expenditure), but a tax-revenue redistribution can be used to

offset this regressivity. In the absence of substitution opportunities (within each of the nine expenditure categories), these results represent highly conservative (worst-case) results, but they illuminate the behavioral response trends while providing a rigorous framework for future work.

EXECUTIVE SUMMARY

With environmental degradation and energy security as serious concerns for most countries, it is important to anticipate how consumer expenditures, vehicle ownership, and usage patterns – and associated greenhouse gas (GHG) emissions – can change under different policies and contexts. Per-capita greenhouse gas emissions in the U.S. are four times the world average, with the transportation sector accounting for close to 30 percent of the nation's total (WRI 2009). A variety of strategies exist to reduce such emissions, including carbon taxes, capping emissions, automotive designs, fuel-source alternatives, vehicle feebates, gas pricing policies, and travel-demand management. This work analyze and compare such policies, and consists of two parts.

The first part relates to the light-duty vehicle fleet evolution the U.S. households. Light-duty vehicle ownership decisions impact fleet composition, total vehicle miles traveled (VMT), fuel consumption, GHG emissions, congestion, tolling revenues, and road safety. Plug-in hybrid electric vehicles (PHEVs) and hybrid electric vehicles (HEVs) have emerged as important alternatives to combat GHG emission from the transportation sector. Thanks to such linkages, transportation planners, engineers, and policy makers have strong interest in accurately forecasting future vehicle fleet attributes (and associated emissions, gas-tax revenues, crash outcomes, etc.) including market for HEVs and PHEVs.

This work makes use of a microsimulation framework, with embedded transaction, vehicle choice and vehicle usage models, to forecast the U.S. vehicle fleet's composition and associated GHG emissions, from 2010 to 2035, under nine different scenarios, including variations in fuel and PHEV prices, new-vehicle feebate policies, and land-use-density settings. Twenty-five-year simulations at gas prices at $7 per gallon resulted in the second highest market share predictions (16.30%) for PHEVs, HEVs, and Smart Cars (combined) — and the greatest GHG-emissions reductions. Predictions under the two feebate policy scenarios suggest shifts toward fuel-efficient vehicles, but with vehicle miles traveled (VMT) rising slightly (by 0.96% and 1.42%), thanks to lower driving costs. The stricter of the two feebate policies – coupled with gasoline at $5 per gallon – resulted in the highest market share (16.37%) for PHEVs, HEVs, and Smart Cars, but not as much GHG emissions reduction as the $7 gas price scenario. Total VMT values under the two feebate scenarios and low-PHEV-pricing scenarios were higher than those under the trend scenario (by 0.56%, 0.96%, and 1.42%, respectively), but only the low-PHEV-pricing scenario delivered higher overall GHG emission estimates (just 0.23% more than trend) in year 2035. The high-density scenario (where job and household densities were quadrupled) resulted in the lowest total vehicle ownership levels, along with below-trend VMT and emissions rates. Finally, the scenario involving a $7,500 rebate on all PHEVs still predicted lower PHEV market share than the $7 gas price scenario (i.e., 2.85% rather than 3.78%).

Results from the first part suggest that a gas price of $7 per gallon or a feebate policy (coupled with gas price of $5 per gallon) will have more of an impact on ownership shares, as well as producing lower CO2e emissions, across scenarios. While only a 29% population-weighted-share of respondents expressed support for a feebate policy, and only 35% (weighted) intend to buy a PHEV if it costs just $6,000 more than its gasoline counterparts, greater support for such policies and more widespread use may emerge if marketing is strategic and pronounced, charging infrastructure is well advertised, HOV-lane priorities and other perks are provided to PEV owners, power pricing levels facilitate vehicle-to-grid interactions, battery prices fall, and so forth. Nonetheless, this work helps in anticipating how vehicle ownership and usage patterns and associated emissions might change under different policies and contexts.

The second part of this report relates to the welfare analysis of carbon taxes and carbon caps. In the past few years, climate change has emerged as our planet's top issue. With impacts of climate change becoming increasingly visible, policy-level solutions to curtail emissions are becoming critical. As a policy level solution for abatement of GHG emissions, proposal considered by U.S. Congress can be grouped into two main classes: emission (or carbon) taxes (on GHG producers) and an upstream cap-and-trade system on industries. This study makes use of various microeconomic methods to compare the GHG emissions and welfare impacts of emission taxes on consumer purchases to those same impacts from a household-level (downstream) cap-and-trade policy. Using data from CEX, a translog utility framework was calibrated and then used to anticipate household expenditures across nine consumer goods categories, including vehicle usage and vehicle expenses. An input-output model was used to estimate the impact of carbon pricing on goods prices, and a vehicle choice model determined vehicle type preferences, along with each household's effective travel costs. Behaviors were predicted under two carbon tax

scenarios ($50 per ton and $100 per ton of CO2-equivalents) and four cap-and-trade scenarios (10-ton and 15-ton cap per person per year with trading allowed at $50 per ton and $100 per ton carbon price). GHG emissions and welfare impacts (equivalent variation) were estimated and compared under each of the scenarios. Two revenue redistribution schemes were tested: uniform and proportional to income. Carbon taxes were found to relatively regressive than a cap-and-trade setting (in terms of taxes paid per dollar of expenditure), but a tax-revenue redistribution can be used to offset this regressivity.

Results suggest that low-income households respond the most under a $100-per-ton tax but increase GHG emissions under cap-and-trade scenarios, thanks to increased income via sale of their carbon credits. High-income households respond the most across all the scenarios under a 10-ton cap (per household member, per year) and trading at $100 per ton scenario. Highest overall emission reduction (47.2%) was estimated to be under $100 per ton carbon tax. High welfare loss was predicted for all households (to the order of 20% of household income) under both the policies. In the absence of substitution opportunities (within each of the nine expenditure categories), these results represent highly conservative (worst-case) results, but they illuminate the behavioral response trends while providing a rigorous framework for future work.

PREFACE

This report consists of two parts. The first part relates to the micro simulation of a synthetic population over time to anticipate Americans' purchases of plug-in hybrid-electric vehicles (PHEVs), the nation's future light-duty-vehicle fleet composition, Americans' vehicle use patterns, and associated greenhouse gas (GHG) emissions. The analysis is based on the modeling results of revealed and stated preference survey questions administered to 1,189 U.S. households in 2009.

The second part of this report relies on an analysis of household purchase data provided by the 2002 U.S. Consumer Expenditure Survey. This work deals with calibrating and applying a transcendental logarthmic utility model to anticipate household purchases with and without GHG emissions taxes in place, the market-price and household-welfare impacts of such taxes, and the relative impacts of a household-level cap-and-trade policy.

Part I consists of Chapters 1 through 6, corresponding to the fleet evolution work. Part II consists of Chapters 6 through 10, for the economic impact analysis work. Appendices A, B, and C are associated with Part I while, Appendices D, E, and F are associated with Part II.

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PART I. LIGHT-DUTY-VEHICLE FLEET EVOLUTION

CHAPTER 1: INTRODUCTION

With increasing industrialization and growing economies, greenhouse gas (GHG) emissions are climbing. The U.S. contains only 4% of the world's population, but contributes 25% percent of the world's GHG emissions (WRI 2009), with per-capita emissions that are four times the world average (WRI 2009). Transportation has always been a major source of U.S. GHG emissions. In 1990, the transportation sector accounted for 25.3% of the total U.S. GHG emissions, rising to 27.9% by 2007 (EPA 2009). A variety of strategies exist to reduce such emissions, including automotive designs, fuel-source alternatives, vehicle feebates, gas pricing policies, and travel-demand management. Desirable long-term impacts include a variety of changes in vehicle ownership patterns (number, type, and holding duration of vehicles), vehicle use patterns, and location choices.

Passenger cars and light duty trucks (LDTs) account for 16% of U.S. GHG emissions (Davis et al. 2009). Light-duty vehicle ownership decisions impact fleet composition, total vehicle miles traveled (VMT), fuel consumption, GHG emissions, congestion, tolling revenues, and road safety (see, e.g., Musti and Kockelman 2010; Lemp and Kockelman 2008). Thanks to such linkages, transportation planners, engineers, and policy makers have strong interest in accurately forecasting future vehicle fleet attributes (and associated emissions, gas-tax revenues, crash outcomes, etc.). Fleet forecasting requires accurate modeling of household transactions (vehicle retirement, replacement, and purchase decisions), vehicle choice, and travel decisions.

This work's fleet-forecasting framework is inspired by Musti and Kockelman's (2010) modeling of the Austin, Texas household fleet over a 25-year period. This work makes use of a very similar microsimulation framework, with embedded transaction, vehicle-choice, and vehicle-usage models, to forecast the U.S. vehicle fleet's composition and associated GHG emissions from 2010 to 2035, under a variety of policy, technology, and gas-price scenarios. Much of this report is summarized in the author's *Transportation Research Record* paper titled, "The Light-Duty-Vehicle Fleet's Evolution: Anticipating PHEV Adoption and Greenhouse Gas Emissions across the U.S. Fleet" (Paul et al. 2011). The following sections present details of related literature, data sets, model specifications, and the 25-year simulation results. This report concludes with a summary of findings and recommendations for policy and future work.

CHAPTER 2: LITERATURE REVIEW

Transportation engineers, planners, and policy makers have great interest in accurately estimating future fleet attributes and evaluating strategies aimed at reducing GHG emissions and fuel use. This chapter reviews the related literature, with Section 2.1 focusing on GHG emissions-reduction strategies, Section 2.2 giving an overview of advanced vehicle technologies (mainly plug-in electric vehicles [PEVs]), and Section 2.3 covering various past vehicle ownership models.

2.1 GHG EMISSIONS-REDUCTION STRATEGIES

A variety of contexts and strategies exist to reduce GHG emissions from the transportation sector, including reliance on more energy-efficient vehicles, alternative fuels (such as biodiesel and ethanol), and vehicle-use reductions. Scenarios examined here directly impact purchase decisions as well as, in some cases, vehicle use. These include fuel-price increases and feebates, along with PEV-price reductions and higher land use densities.

2.1.1 Fuel Taxes and Feebates

In the case of transportation, carbon-related taxes can be levied directly on fuel or VMT, with charges effectively based on fuel economy and vehicle use. Gallagher and Collantes (2008) used the Energy Information Administration's general equilibrium model of U.S. energy markets (i.e., the National Energy Modeling System [NEMS]) to examine a number of transportation policies to reduce GHG emissions and dependency on imported oil. Their choice of carbon taxes (starting at $10 and $30 per ton of CO2e) increased the cost of driving marginally, whereas scenario involving starting fuel tax at 50 cents per gallon and 10% annual escalation generated much greater levels of emission reduction (more than 14% compared to base case).

Many car buyers appear to be quite short-sighted when evaluating the benefits of higher fuel-economy vehicles, for purchase (and lease) (Goldberg 2008; Greene et al. 2005; Bhat and Sen 2006; McManus 2007). Corporate Average Fuel Economy (CAFE) regulations help address this issue, to some extent (by forcing manufacturers to comply with fuel economy targets, essentially, rather than relying on consumer demand to push the manufacturers to such economies).

Established in 1975 under the Energy Policy and Conservation Act, the CAFE program has clearly improved the U.S. light-duty-vehicle fleet's fuel economy (NRC 2002). Under the 2007 Energy Independence and Security Act, CAFE standards will tighten significantly by 2020 (up to an estimated 35 mpg – from 27.5 mpg (LDTs) and 23.5 mpg (passenger cars) in 2010) (EIA 2010).

Feebates are another version of this notion, providing rebates to those purchasing relatively fuel-efficient vehicles (i.e., those above some mpg threshold), and charging a fee otherwise. Revenue neutrality can be accomplished by appropriate choice of the threshold or pivot point (point at which there is no fee or rebate) in the feebate schedule, and by appropriate rates of fee and rebate increase (per mpg that the vehicle's fuel economy deviates from the target). Train et al. (1997) examined six different revenue-neutral feebate systems and estimated a 10 to 14% improvement in CAFE values (of new sales) under each system by 2010 (relative to 1995). Most of this response resulted from manufacturers supplying more fuel-efficient vehicles, rather than consumers shifting to more fuel efficient cars.

The effectiveness of feebates depends on how much consumers value fuel savings. Greene et al. (2005) tested the sensitivity of feebate policies to the cost of the fuel-saving technology and price elasticities of vehicle demand. They estimated that 95% of the fuel economy increase comes from technological changes and not from changes in vehicle mix sold. They concluded that consumers' valuation of fuel economy differences is critical to policy outcomes. If consumers consider only the first three years of fuel savings, then improvements will be very low.

Feebates may also lead to vehicle downsizing, to achieve better CAFE. Greene (2009) created a footprint-based feebate system, where the target (or pivot) fuel economy is a continuous function of footprint (track width times vehicle length). Such policy removes the clear incentive for manufacturing and buying smaller vehicles but preserves the incentive for selecting a fuel-efficient vehicle.

Johnson (2005) proposed a feebate policy for reducing vehicular emissions based on Sweden's successful oxides of nitrogen (NOx) program, which has a class-based feebate system. Vehicles are divided into different groups (having similar characteristics), with a separate feebate schedule for each group. Johnson (2005) concluded that under typical market conditions this approach can increase the emission-reduction incentives by a factor of three relative to a conventional feebate that treats all (light-duty) vehicles as functionally equivalent commodities.

Since feebate systems promote greater fuel efficiency, they also promote a rebound effect, by lowering per-mile driving costs, on average. (See, e.g., Haughton and Sarkar [1996], Greene et al. [1999], Small and Dender [2007], and Hughes et al. [2008]). Greene (1999) estimated a 20-percent rebound effect for U.S.-household vehicle travel (so that the lowered cost of travel offsets 20 percent of the expected fuel or GHG savings, due to longer driving distances). Train et al.'s (1997) look at feebate systems suggested a 25% effect. Greene (2007) and many others believe that fuel taxes and feebates work better in tandem, to avoid such rebound effects while more directly reflecting costs of petroleum consumption (e.g., energy security issues and climate change concerns).

Tightening CAFE standards will promote manufacturing (and presumably vehicle-pricing) changes, along withtechnological advances. For example, Liu et al. (2011) expect that feebates will drive the sales of many hybrid electric vehicles (HEVs). The next section gives a brief overview of some of the upcoming advanced vehicle technologies, focusing on plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

2.1.2 Advanced Vehicle Technologies

The world is witnessing the development and deployment of advanced vehicle technologies, thanks in part to stricter fuel economy and emission standards as well as a growing need (and desire) to reduce oil dependence. Significant emphasis has been placed on developing electric power trains. These advanced vehicle technologies include HEVs, PHEVs, extended-range EVs, BEVs, and fuel cell vehicles (FCVs).

Kromer and Heywood (2007) define HEVs, PHEVs, BEVs, and FCVs as follows:

> HEV: A vehicle that integrates a gasoline-powered engine with an onboard electrical energy storage system to deliver motive power to the wheels. In a hybrid electric vehicle, the primary energy is sourced from gasoline.

PHEV: A vehicle that uses both gasoline and off-board electricity to deliver motive power. In charge-depleting mode, the PHEV draws energy primarily from the battery; once the battery state-of-charge is depleted, it switches to charge sustaining mode, in which primary energy is sourced from gasoline. "PHEV-XX" refers to a plug-in hybrid with a given electric range; for example a "PHEV-30" is estimated to have a 30 mile electric range.

BEV: A vehicle that receives all motive power from off-board electricity.

FCV[1]: A vehicle that uses a proton-exchange membrane (PEM) fuel cell powered by stored onboard hydrogen to generate electricity.

Grid-enabled or PEVs can be grouped as BEVs, PHEVs, and extended-range electric vehicles (eREVs). eREVs are essentially BEVs with an onboard gasoline-powered generator to provide electrical energy once the initial charge is depleted (Tate et al. [2008]). Both PHEVs and eREVs solve the range-anxiety problem of BEVs.

The Chevrolet Volt eREV, Toyota Prius PHEV, Nissan Leaf BEV, and Ford Focus BEV promise a more fuel-efficient fleet[2], but actual GHG reductions depend on the sources of electricity and the percentage of VMT powered by electricity. In spite of clear need, a worldwide methodology for estimating fuel consumption and emissions factors has not been established, largely because of distinct driving cycles (e.g., urban versus rural, freeway versus local street, congested versus uncongested). To accurately measure GHG emissions from PHEVs, it is important to know the percentage of miles traveled on electricity. The percentage of electric miles for a PHEV with a certain all-electric-range (AER) can be estimated using utility factor (UF) curves. To define UF, it is important to know how a PHEV operates. A PHEV operates in two modes: charge depleting (CD) and charge sustaining (CS). In CD, the PHEV operates solely on battery power; in CS it

[1] FCVs are long way off as a technology and faces steep challenges as lack development of hydrogen fuelling infrastructure and high costs to be deployed (Kromer and Heywood [2007]).
[2] The Volt was released to individuals in California, Washington D.C., Michigan, New York, New Jersey, Connecticut, and Austin in 2010 (www.chevrolet.com). The Prius PHEV is coming in 2012 (http://www.nytimes.com/2010/09/14/business/14auto.html?_r=1&hpw). The Leaf launched in California, Washington, Oregon, Arizona, and Tennessee in 2010 (www.edmunds.com), and the Ford Focus BEV is to emerge in 2011 (according to www.ford.com).

operates on a blend of power from the battery and gasoline (Simpson 2006; Markel 2006a). Thus, UF for a PHEV is defined as:

$$UF = \frac{Miles\ Driven\ in\ CD\ Mode}{Total\ Number\ of\ Miles\ Driven} \qquad (2.1)$$

A UF curve is estimated by plotting the fraction of electric miles against the AER of the PHEV, by dividing daily miles travelled into CS or CD miles. Examples of UF curves can be found in Markel and Simpson (2006), Kromer and Heywood (2007), and Gonder et al. (2009).

Consumer acceptance and adoption of PEV technologies depends on pricing, marketing, and owner experiences. The government's role in effectively marketing and promoting these vehicles may be crucial. For example, charging infrastructure availability can play an key role in promoting the market for PHEVs and BEVs (Lin and Greene 2011). The next section gives an overview of existing vehicle-ownership studies, which form the basis for strategic portions of this research.

2.2 Vehicle Ownership Models

Past studies of vehicle ownership emphasize the impacts of vehicle attributes, household characteristics, and environmental variables (such as fuel prices and taxes) on vehicle-choice decisions. Lave and Train (1979) estimated a multinomial logit (MNL) model for vehicle choice, with household and vehicle characteristics, gasoline prices, and taxes as explanatory variables. Manski and Sherman (1980) estimated MNL models for one- and two-vehicle households and concluded that most vehicle performance attributes have relatively little impact on choice, while price and operating and transaction costs are practically (and statistically) significant. Berkovec and Rust (1985) estimated nested logit (NL) models and noted that consumers are more likely to stick with past or current vehicle make and model rather than replacing with a different make and model. Findings from these studies emphasize that various vehicle-specific attributes (e.g., purchase price, fuel economy, and cabin room) have significant impact on vehicle choice, consistent with findings found in Mannering et al. (2002), Mohammadian and Miller (2003a), Train and Winston (2007), and Nolan (2010).

Neighborhood attributes and owner attitudes can also play substantive roles. Potoglou and Kanaroglou (2008) found that transit proximity, diversity of land use, and home-to-work distances were significant determinants of vehicle ownership in Hamilton, Canada after controlling for socioeconomic characteristics. Bhat et al. (2009) examined the effect of built environment characteristics and concluded that neighborhoods high in density of both residential and commercial uses are associated with smaller-sized vehicles. Zhao and Kockelman (2001) found household size, income, home-neighborhood population density, and vehicle prices to be important predictors of a household's vehicle counts by body types (e.g., number of SUVs versus passenger cars owned).

Choo and Mokhtarian (2004) determined that consumers' travel attitudes, personalities, lifestyles, and mobility are helpful predictors of vehicle choice decisions. Kurani and Turrentine (2004) concluded that households generally do not pay much attention to a given vehicle's fuel cost (per mile, per year, or over a lifetime) unless they are operating under tight budgetary constraints; however, they do pay attention to fuel prices (per gallon). Busse et al. (2009) found that market *shares* of *new* vehicles in the U.S. (by fuel economy category) tend to adjust to offset gas-price shifts, while *used-vehicle prices* adjust directly. Mannering and Winston (1985) estimated a dynamic model for vehicle choice and use, reflecting past choices. Their results suggest that consumers go for a vehicle with higher brand loyalty, ceteris paribus. Berkowitz et al. (1987) reported inertia effects in (short-run) vehicle use and fuel consumption data, in response to energy-related policies. Feng et al. (2005) estimated an NL choice model coupled with a use model and predicted that higher gasoline prices and rising registration taxes as vehicles (and their emission-control technologies) age will lead to emissions reductions. Sallee et al. (2010) used transactions data from wholesale used-car auctions between 1990 and 2009 to discover that purchasing wholesalers fully value (at 5% [baseline], 10%, and 15% discount rate) efficiency lifetime of expected fuel savings from higher fuel-economy vehicles.

Vehicle choice and transaction models have been increasingly used for forecasting market shares of alternative-fuel vehicles and evaluating climate and energy policies. Mohammadian and Miller (2003b) estimated changes in household size and job status (of household members) to be significant determinants of transaction decisions. Gallagher et al. (2008) concluded that higher gasoline prices and heightened preferences for energy security or environmental protection tend to lead to greater rates of HEV adoption than government incentives (which often come after purchase, in the form of annual-income tax rebates, for example). Musti and Kockelman (2010) estimated the highest future PHEV-plus-HEV share for Austin, TX (19% by 2034) to emerge under a feebate policy scenario (with 30 mpg pivot point and fee/rebate at an average rate of $200 per mpg).

2.3 Summary

This chapter introduced the problem of GHG emissions from U.S. transport. Fuel taxes, feebates, fuel economy, and emission standards are some of the policy-based solutions. The effectiveness of these policies will depend, in part, on the availability and adoption of advanced fuel and vehicle technologies. Such policies can be evaluated by understanding household vehicle ownership and usage patterns. The work presented in this report relies on the growing literature, as described above, for specification of behavioral models and scenario simulations. The model runs anticipate adoption of HEVs and PHEVs across the U.S. personal-vehicle fleet over the next 25 years, under trend conditions, higher gas prices, feebate policy settings, and other scenarios.

CHAPTER 3: DATA DESCRIPTION AND MODEL CALIBRATION

3.1 Introduction

This chapter describes the data used in this study of fleet evolution. Data were obtained via an online survey issued in the Fall of 2009, using a pre-registered sample of households/respondents from across the U.S., as maintained by Survey Sampling International (SSI). Musti and Kockelman (2010) enhanced the survey they had used for collection of Austin, Texas data[3], for use in this national online survey, and assembled the respondent data (as obtained by SSI). The following sections present details of the survey's design, sample's weighting (for population correction), household synthesis (for microsimulation), and analysis of survey responses under various contrexts.

3.2 Questionnaire Design

The survey questionnaire is divided into different sections with questions on respondents' current and past vehicle holdings and vehicle-use details, future vehicle-choice elections, climate and energy policy opinions, and demographics (as shown in Appendix A). In the stated preference (SP) section, respondents were presented with 12 very popular (high share in vehicle sales in the year 2008 and 2009) vehicle choices covering a wide range of price, fuel economy, and body types under the four different contexts. The major body types were represented by Honda Civic (Compact car category), Toyota Yaris (Small car), Nissan Maxima (Large car), Lexus ES 350 (Luxury car), Honda Odyssey (Minivan), Ford F-150 (Pickup), Honda Odyssey (minivan) , Ford Escape (SUV), a Prius hybrid electric vehicle (HEV), a Prius plug-in hybrid electric vehicle (PHEV), a Mercedes Smart Car, and a Hummer. The PHEV[4] was assumed to have a 30-mile,[5] all-electric range requiring about 250 watt-hours per mile, with an 11-gallon gas tank, resulting in a total range of 500 miles. All other attributes of the PHEV30 matched a Toyota Prius. The

[3] For example, questions exhibiting higher non-response in the Austin survey were modified. A question on a Leaf BEV was added. Experts in the field of travel behavior analysis, vehicle fleet modeling, alternative fuels, energy policy, and transport-survey design were contacted, and their suggestions were incorporated.

[4] The PHEV's effective fuel economy and purchase price were estimated using information from Kurani et al. (2009), Axsen and Kurani (2008), Markel (2006a,b), and CalCars.com. While the Chevrolet Volt is the first PHEV to hit the U.S. market, its roll-out came after the SP survey. Toyota's Prius was already available to respondents, making the Prius PHEV a more realistic choice option for this SP experiment.

[5] There may be greater variation beyond PHEV30, but incorporating those was beyond the scope of this work.

scope of this study did not allow inclusion of more vehicle types. Even though the list of 12 vehicles covers almost all body types, it misses the mid-size car category. The four question contexts presented to each respondent consisted of a base-case context, two increased-gas-price contexts ($5 and $7/gal fuel costs were provided), and an external-costs context (with GHG and other emissions' social-cost impacts estimated for each vehicle – assuming driving distances of 15,000 miles per year, which is typical of new U.S. passenger vehicles [NHTS 2009], with close to 11,000 miles being electrified).

Other questions included opinions about potential climate and energy policies and the respondent's willingness to adopt advanced vehicle technologies under different fuel-cost and purchase-price settings. Responses to these questions provide important information regarding support for these policies and for the design of future policies. The final section requested demographic details, including the respondent's age, gender, household size, household income, and home address. These demographic variables were used in the behavioral model estimation to achieve segmentation among the population, and they allowed greater variation at the time of application.

3.3 Summary Statistics

Table 3.1 compares key demographic variables obtained in the (unweighted/uncorrected) national survey to U.S. ACS data (which rely on 2006 through 2008 averages). The sample and national averages are quite similar except for slight variation among a few variables. The sample's household income is 19% lower ($59,882 vs. $71,128) than the national average. The average number of vehicles per household is about 15 percent less than the ACS average (similar to the income effect). Nevertheless, the share of online respondents holding a bachelor's degree or higher is 25 percent more than the corresponding ACS proportion. Though most of the key variables are close to their population estimates, each household record was appropriately weighted in order to facilitate relatively unbiased model calibration and application. The following section describes the weights estimation procedure and how these were used to construct a synthetic population.

Table 3.1 Sample Summary Statistics (Unweighted) vs. U.S. Population Average

Variable	Minimum	Maximum	Mean	Std. Deviation	ACS Average
Household variables					
Male indicator	0	1	0.4685	0.4992	0.4931
Age of respondent (years)	20	70	46.49	15.17	47.51
Household (HH) size	1	9	2.463	1.293	2.600
Number of household workers	0	5	1.232	0.8930	1.220
Number of household vehicles	0	5	1.596	0.8227	1.692
Age of oldest household vehicle (years)	0	77	10.22	7.272	-
Annual VMT per household vehicle (miles)	500	60,000	11,183	7,671	-
Annual household income ($/year)	10,000	200,000	59,882	41,045	70,096
Income per HH member	$1,667	$200,000	$31,770	$28,669	-
High income HH indicator (>$75,000/year)	0	1	0.266	0.442	-
Large HH size indicator (5+ membe	0	1	0.082	0.28	-
Location variables					
Job density (# of jobs/sq mile in hon ZIP code)	0.053	204,784	1,454	8,525	-
HH density (# of HHs/sq mile in hor ZIP code)	0.187	37,341	1,039	2,095	-
Attributes of owned vehicles					
Fuel cost ($/mile)	0.0543	0.1667	0.1057	0.0374	-
Purchase price ($)	15,000	61,500	28,500	12,184	-
Intended transaction decisions in the coming year					
Acquire a vehicle	0	1	0.1775	0.3822	-
Dispose of currently held vehicle	0	1	0.0227	0.149	-
Replace a currently held vehicle	0	1	0.0538	0.2257	-
Do nothing	0	1	0.7317	0.4432	-

Note: All table values come directly from survey responses, except for fuel cost, which is derived from fuel economies obtained in *Ward's Automotive Yearbook* (2007), and job and household counts by zip code, which come from the U.S. Census Bureau's ZIP Code Business Patterns (2007). The American Community Survey (ACS) average used comes from nation-wide 2006–2008 data. Fuel costs were estimated using EPA-reported fuel economies (based on 45% highway and 55% city driving).

3.4 Weighting and Synthetic Population Generation

The first step in data analysis was to make the sample representative of the U.S. population Population weights were computed by dividing the sample into 720 multi-dimensionalcategories, based on respondent gender (male/female), age (six categories), employment and student status, household size (1, 2, 3, 4, 5+), and household income categories of low (<$30,000 per year), medium ($30,000 to $75,000), and high (>$75,000). The ratios of counts from the nation's 2008 American Community Survey's (ACS 2008) microdata sample to the survey's sample counts were normalized for each of the categories. Categories with very few data points were merged with adjoining bins. Since some (less than 2 percent) of the records lacked demographic information, 1,189 usable data points (out of 1,210 initially collected) were left at the end of this exercise.

As shown in Table 3.1, averages of key household variables match with those of the ACS quite closely. So weighting of these variables did not significantly affect mean values. The most noticeable shifts between weighted and un-weighted averages were for the male indicator (from 0.4685 to 0.4850), respondent age (from 46.49 to 47.18 years), and number of household workers (from 1.23 to 1.26).

The synthetic population used for microsimulation in this study was also constructed from the survey sample. Households in the survey sample were scaled up in proportion to their corresponding weights to construct a synthetic U.S. population of manageable size (50,016 synthetic households, to represent the nation's 115 million year-2010 households).

3.5 Survey Response Analysis

Figure 3.1 presents weighted responses for vehicle choices under different question settings. The choices that respondents make under different SP contexts give important information about the triggers that may influence their future choices. Under the base-case SP-question context, the most popular choices were compact cars and SUVs (at 23% and 19% weighted choice shares). Under the gas price contexts of $5 and $7 per gallon, the compact car and HEV received the most votes (22% and 19% at $5/gal, respectively, and 23% and 24% at $7/gal). Under the final, environmental-costs question context, the Prius HEV dominated (21.5%), followed by compact cars (20.7%). There was not much variation in the shares of compact, sub-compact, and Hummer classes across the four question settings. As expected, shares of van, SUV, CUV[6], pickup truck,

[6] Cross-over utility vehicles (CUVs) borrow features from SUVs but have a car platform for lighter weight and better fuel efficiency.

luxury car, and large car options decreased under the higher-gas-price settings, while popularity of the Smart Car, HEV, and PHEV rose.

Of particular interest is the fact that the environmental-cost context's results closely mimic those of the $5/gal context, though the environmental costs (at just 6.4¢/mile for the pickup option vs. 0.5¢/mile for the PHEV) are far lower than the *added* gas costs of a $5/gal context (which range from 14¢/mile for the Hummer to just 0.5¢ for the PHEV—where much of the power is provided by electricity [close to 75%]). It appears that simple labeling or astute advertising may shift perceptions quickly in the direction of a cleaner fleet. Though results of SP experiments do not reflect respondents' actual behavior, they still provide important information in terms of changes in preferences under different settings.

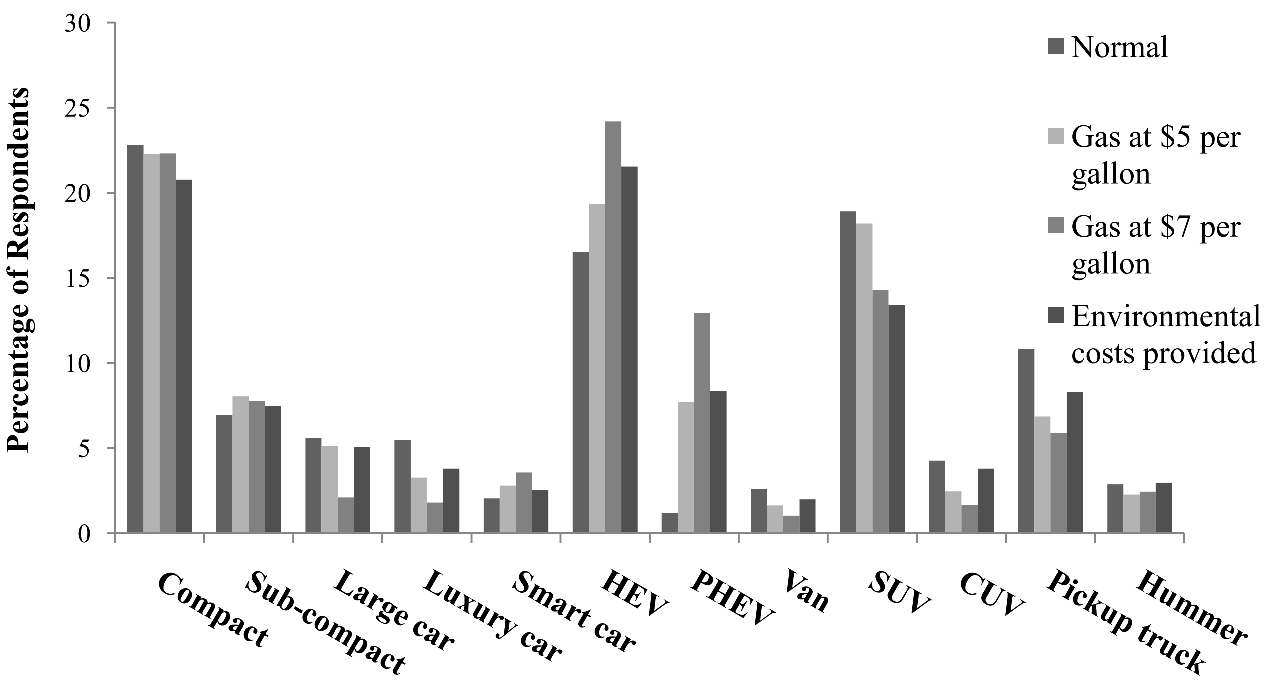

Figure 3.1: Vehicle Selection under Different Settings (Weighted Responses)

It is equally important to know the reasons why consumers did not buy certain vehicles as it is to know the reasons for buying a new vehicle. Figure 3.2 summarizes reasons that survey respondents gave for not buying the last two vehicles they had considered purchasing. Unsurprisingly, "too-high purchase price" dominated, followed by "less-desired vehicle type" and “too-low fuel economy” – which garnered 27.3%, 11.5%, and 8.9% of the (weighted) responses, respectively. While Musti and Kockelman (2010) also found fuel economy to score third highest among Austin respondents’ criteria for a future (not past) vehicle-acquisition event, and place first once all top-three ranks’ shares were added, consumers’ recognition of fuel economy did not emerge strongly in parameter estimates for the vehicle choice models. Greene’s (2010b) extensive review reports a lack of consensus among existing studies regarding importance of fuel economy in households’ vehicle choice decisions. Of course, the U.S. population does differ from that of Austin (which boasts a highly educated and environmentally conscious population, as noted in Smith et al. [2009]), and used-vehicle purchase prices may much better reflect gas-price conditions (George and Mayor [1983], Kahn [1986], CBO [2008], Smith et al. [2009], Sallee et al. [2010]).

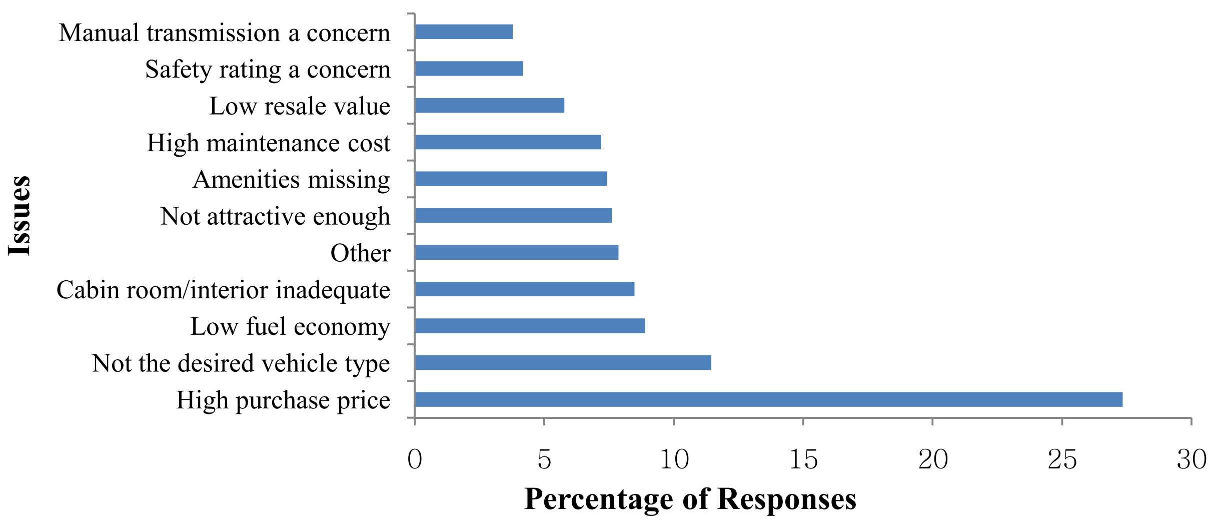

Figure 3.2: Issues with Vehicles Not Bought During Recent Purchase (Weighted Responses)

Opinions on potential climate policies not only help in evaluating these policies but can also be critical for designing future policies. Figure 3.3 presents the responses in support or opposition of a specific policy. The specific feebate schedule presented to the respondents was pivoted at/centered on a 30 mpg target (zero-fee, zero-rebate) fuel economy, with an average fee/rebate of $200 per mpg of deviation from that target. Only 29% of the (population-corrected) respondents expressed their support for this specific feebate policy, compared with 63% support in Musti and Kockelman's (2010) Austin survey (as population corrected for the Austin region). About 25% of the respondents remained neutral, while close to 30% (the highest share) strongly opposed this policy. But 41.5% (weighted) indicated that they would seriously consider buying a hybrid-electric (HEV) version of a standard vehicle model costing $3,000 more if they were going to buy a new vehicle at the time of survey. Around 36% would consider buying a PHEV at $6,000 more than a comparable gasoline-powered vehicle under current gasoline price uncertainties. Overall, 55.5% reported access to electricity in their garage or a carport near their residential unit. As stated earlier (section 2.1.2), the Chevrolet Volt eREV and Nissan Leaf BEV were released in 2010 – but only in selected launch markets, to facilitate a successful rollout. Thus, sales shares are still very low, well below people's stated willingness, even with their $7,500 rebates.

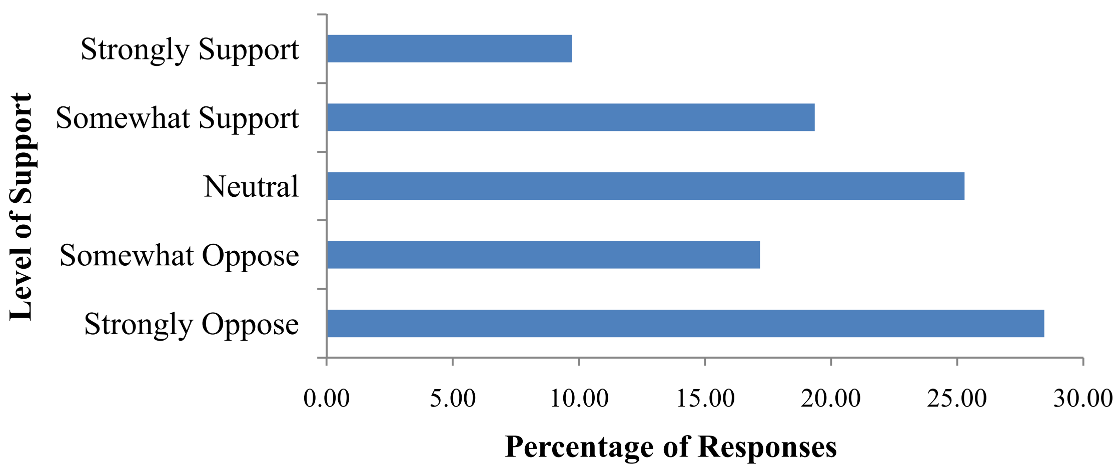

Figure 3.3: Support for a Feebate Policy (Weighted Responses)

When asked about the responses they would consider in the face of a gasoline price increase to $6/gal, 11.5% (weighted) indicated that they would consider buying a hybrid version of their current vehicle by paying an additional $2,500, while only 5.15% (weighted) of the respondents would consider buying a PHEV version of their current vehicle by paying an additional $4,000. Figure 3.4 summarizes these weighted responses. A majority of the respondents (43.3%, weighted) indicated that they would "adapt to the change" in some way. When those who indicated that they would adapt were asked the ways in which they would expect to adapt, and presented with options of using public transportation more, carpooling, walking/biking,cutting back on other expenditures, and an "other" category, most (43.4%, weighted) indicated that they would cut back on other expenditures, as shown in Figure 3.5.

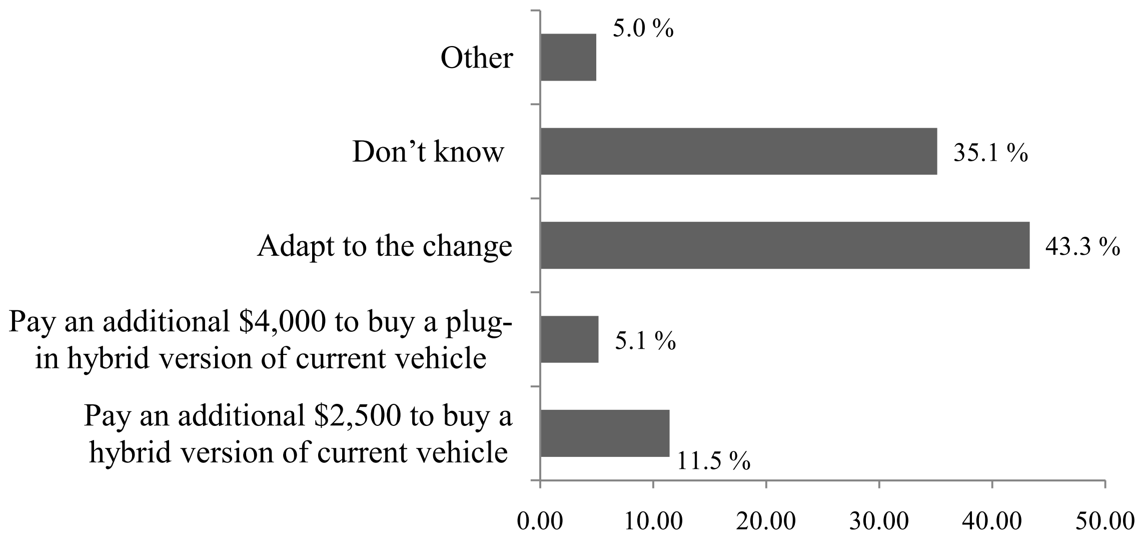

Figure 3.4: Choices under Gasoline Price Rise to $6/Gal (Weighted Responses)

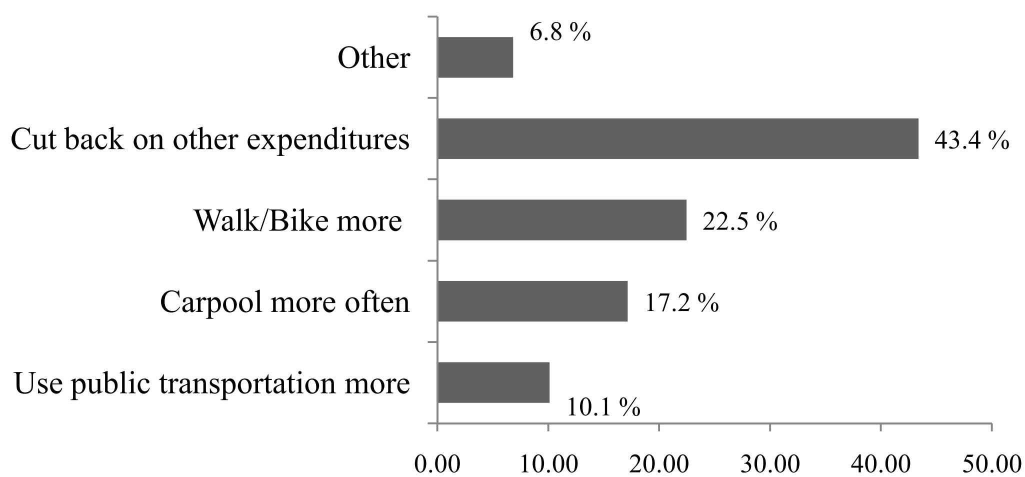

Figure 3.5: Responses to Question on Adaption to the $6/gallon Gas-Price Change? (Weighted Responses)

The next most popular gas-price-adaptation option was walking and biking more often (22.5%, weighted), closely followed by carpooling (17.2%), and finally public transportation (10.1). Just 6.84% (weighted) indicated that they would resort to "other options" with telecommuting being the most common response.

While responses to these SP questions may not represent respondents' actual behaviors, they do give an indication of the directions that people may take in relation to these policies and pricing contexts. Though most of these context-based shares were not used for any model estimation in this work, the values provide important information about vehicle purchasing patterns. The next chapter discusses the details of model calibration and interpretation of the resulting parameter estimates.

CHAPTER 4: MODEL ESTIMATION AND CALIBRATION

At the core of any microsimulation process lies the behavioral models for various decisions undertaken by households/individuals. Models were estimated using both the stated and revealed preference data sets. Covariate inclusion was decided on the basis of statistical significance (essentially a p-value under 0.10) following a process of stepwise addition and deletion (of covariates). Since the synthetic population was constructed using the survey sample – which includes information about the number and type of vehicles held by each household, a model to predict the number of vehicles owned by the synthetic households was not required. Other models that were estimated include a model for household transactions (buy a vehicle, dispose of a vehicle, or replace a vehicle), models of vehicle ownership based on revealed and stated preferences, and finally a model for annual vehicle miles of travel (VMT) per household vehicle. Details of model calibration and inferences are provided in the following sub-sections.

4.1 VEHICLE TRANSACTIONS MODEL

Survey respondents were given four choices for their intended transactions in the coming year: acquire a vehicle, dispose of one, replace a vehicle, or do nothing. Out of the 1,103 respondents, 18% (weighted) indicated their intent to acquire an added vehicle in the coming year, 2.3% (weighted) felt they were likely to simply dispose of an existing vehicle, 5.5% (weighted) expected to replace a vehicle, and the remaining 74.2% planned to maintain their current fleet. Figure 4.1 summarizes these responses.

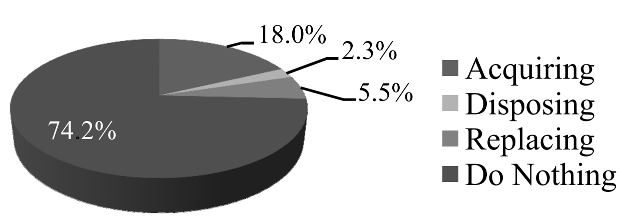

Figure 4.1: Intended Transactions Over the Coming Year (Weighted)

Table 4.1 presents all parameter estimates. Again, this model is also estimated on a relatively small sample with some evident optimism bias (i.e., over-acquisition outstripping loss of vehicles, resulting in excessive vehicle ownership levels after 10 or more years). Therefore, the model's ASCs were adjusted to match the predicted increase in vehicle count to the U.S.'s 2000-2008 vehicle-count growth rates (of 1.43% per year, according to the Bureau of Transportation Statistics' National Transportation Statistics). These adjusted ASCs are presented in Table 4.1's final column.

Table 4.1: Annual Household Transactions Model Estimates (Weighted MNL)

Variable	**Coefficient**	**T-stat**	**Re-estimated ASCs**
Acquire (indicator)	-	-	-1.022
Dispose (indicator)	-3.981	-16.78	-3.500
Replace (indicator)	-2.557	-13.67	-2.100
Male respondent x Replace	-0.7601	-2.69	-
Age of respondent x Acquire	-0.0335	-8.82	-
Number of children x Replace	0.4153	3.62	-
Number of workers x Acquire	0.3019	3.07	-
Number of vehicles in the household x Acquire	-0.5748	-4.37	-
Maximum age of vehicle in household x (Acqui Dispose)	0.0551	5.35	-
Low income household (<$30k) x Acquire	-0.5231	-1.88	-
Household density x Dispose	7.81-05	1.27	-
Log Likelihood at Constants	-921.0		
Log Likelihood at Convergence	-807.2		
Pseudo R^2	0.4721		
Number of households	1103		

Note: Do Nothing is the base alternative.

Results are quite intuitive, suggesting, for example, that households with many vehicles are less likely to acquire a new vehicle to maintain their current fleet. Households with many workers are more likely to acquire another vehicle in the coming year, ceteris paribus. Older respondents appear less likely to acquire a vehicle, and male respondents are less likely to expect vehicle replacement over the coming year. Higher household density zip codes are associated with greater disposal likelihood, which may be due to a lesser need for travel and/or higher congestion levels. Low-income households report lower acquisition likelihoods, which may be due to nonavailability of funds. The vehicle choice decisions which follow the transaction decisions are discussed in the next subsection.

4.2 Vehicle Ownership Based on Revealed Preferences

The national survey collected information on households' current vehicle holding patterns (make, model, and year of manufacture). Survey respondents' current vehicle holdings were grouped into nine vehicle types (for the base-case choice set): subcompact, compact, midsize car, large car, luxury car, van, SUV, CUV, and pickup truck. The 1,079 households in the data set reported owning a total of 1,778 vehicles, with 20% as mid-size cars, 15.5% as compact cars, 16% pickup trucks, 16.4% SUVs, and the remaining 32.1% comprised of CUVs, luxury cars, large cars, and vans, as shown in Figure 4.2.

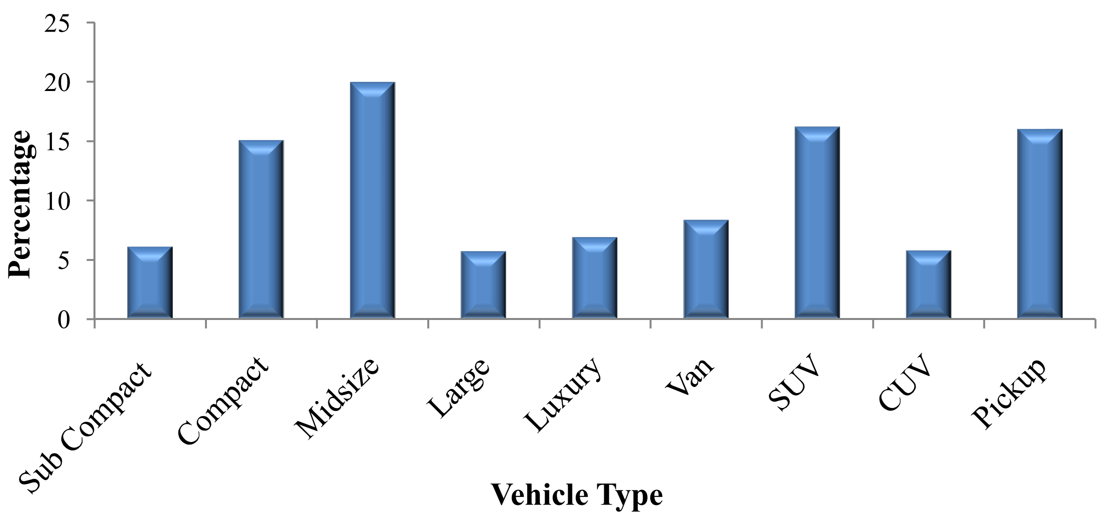

Figure 4.2: Current Vehicle Holdings (Weighted)

The inclusion of various variables in the vehicle-ownership model was inspired by existing literature and the availability of variables in the sampled and thus synthetic population. Multinomial logit (MNL) models controlled for demographic attributes, neighborhood densities, and generic attributes (fuel cost and purchase price) of the nine vehicle-type alternatives. Variables used in this model are defined in Table 3.1 (and its note). Table 4.2 presents the weighted-MNL coefficient estimates for the model of vehicle ownership, based on the 1,778 vehicles reported in the 1,079-household data set.

Table 4.2: Parameter Estimates for RP Vehicle-Type Ownership Model (Weighted MNL)

Variable	**Coefficient**	**T-stat**
CUV	-1.690	-3.64
Large car	-0.7813	-7.05
Subcompact	-1.333	-8.18
Fuel cost (dollars per mile)	-4.448	-2.76
Purchase price (dollars) x 10^{-5}	-3.392	-7.36
Male respondent x CUV	0.6311	2.92
Respondent age x CUV	0.0186	2.44
Number of workers x (CUV, Compact)	-0.3848	-5.51
Large household size (>4) indicator x (Midsize car, Pickup truck, Compact, SUV, Van)	0.9601	3.89
Household income x (Compact, SUV)	4.17E-06	5.02
Number of vehicles in household x Compact	0.1112	1.83
Job density x (CUV, Subcompact, Van)	-8.85E-05	-1.97
Household density x Van	-2.41E-04	-2.49
Household density x (Midsize car, Pickup truck, Compact, SUV)	1.06E-04	2.24
Log likelihood with constants only	-3682.16	
Log likelihood at convergence	-3673.80	
Pseudo R^2	0.0596	
Number of observations	1,778	

Note: Luxury car is the base alternative.

The coefficients corresponding to fuel cost and vehicle purchase price are statistically significant and intuitive. Households with many vehicles are relatively likely to own a compact car. Those of higher income are likely to own a compact car and/or SUV. Households with more workers are less likely to hold a CUV or compact car, and larger households prefer mid-size cars, pickup trucks, SUVs, and vans, probably due to seating capacity and storage space needs. Older male respondents have a higher tendency to own CUVs, everything else constant. This vehicle ownership model (based on revealed preference data) was used to predict which vehicle will be disposed or replaced by the households (by comparing the estimated systematic utility values of all vehicles in the household fleet, and removing those of lowest [estimated] value).

4.3 Vehicle Ownership Based on Stated Preferences

The online survey offered three special vehicle-type categories to respondents: a Prius HEV, a Prius PHEV30 (which does not yet exist), and a Mercedes Smart Car. As mentioned earlier, due the limited scope of this study, a mid-size car option was not provided in the stated preference portion of the online survey. Other than the above-mentioned three vehicles, all revealed-preference vehicle types/categories (except midsize) were provided, along with a Hummer class. Stated preference responses (weighted) are presented in Figure 4.3.

Top choices among respondents were the compact car (22.8% of the weighted/population-corrected sample), SUV (19.0%), HEV (16.5%), and pickup truck (10.8%). The remaining 30.9% elected a subcompact car, luxury car, large car, Hummer, van, Smart Car, or PHEV.

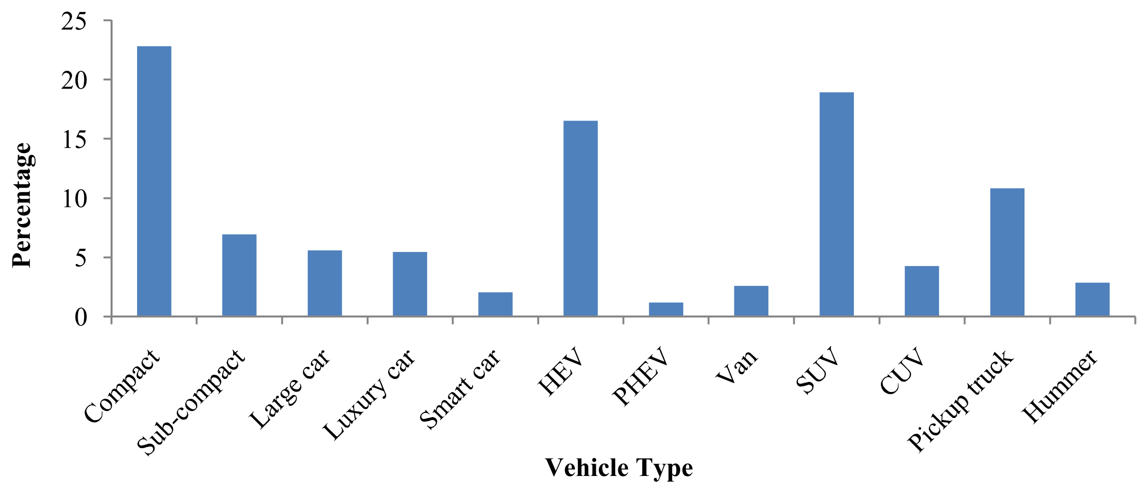

Figure 4.3: Stated Preference for Vehicle Choice – Base Context (Weighted)

One major aim of model application is for predictions to track reality. The predicted shares of vehicles from this model come from a relatively small data set and so cannot closely match recent U.S. sales patterns (according to *Ward's Automotive Yearbook* for 2010, which provides 2008 and 2009 model year sales numbers). The purchase model based on SP responses for next-vehicle-acquisition over-predicted sales shares of HEVs, compact cars, and SUVs and under-predicted subcompact, CUV, and pickup truck shares. The model also did not have midsize cars as an alternative (mainly due to space limitations in the survey form). PHEVs and HEVs also were only offered as a mid-size body type, when the hope is that other options will emerge (with plug-in SUVs already planned for U.S. production). Stricter regulation of U.S. fleet fuel economy (through CAFE standards) will motivate manufacture of more hybrid vehicle designs (NRC 2002).

Although the survey did not provide conventional midsize cars or non-car PHEVs and HEVs as alternatives, these were included in the behavioral model by estimating ASCs (while recognizing their likely costs and other attributes). The introduction of HEV and PHEV versions of SUVs, pickups, and vans, along with midsize cars increases the number of alternatives to 19 vehicle types. Of course, the new PHEVs and HEVs enjoy a higher fuel economy than their internal combustion engine (ICE) counterparts, but at a higher price. Since these vehicles are not yet available in the market, their prices and fuel economy were assumed based on the percentage differences observed in these variables among the existing HEV and ICE models (e.g., ICE versus HEV Chevrolet Tahoe, ICE versus Hybrid Honda Civic, and Ford Focus ICE versus HEV). PHEVs come with a price premium of $5,000 to $6,000 on smaller models (TEP 2011). The actual premium for a PHEV depends on the architecture under consideration, battery size, and other factors, and should fall over time, due to technological advances and economies of scale in production. Estimating these premiums and the trajectory of price reduction is beyond the scope of this study, so prices were held constant over the 25-year simulation. Presumably other vehicles' prices will also fall somewhat, and/or vehicle qualities will improve, so it is nearly impossible to anticipate all variations. The new PHEVs considered in this study are assumed to have a modest AER of 25 to 30 miles, battery sizes from 10 to 15 kWh, and price premia of $8,000 to $10,000. Assumptions relating to these new vehicles along with original 12 offered in the survey are presented in Appendix B.

In order to incorporate the new vehicle options, an midsize-car ASC was added to the original model (with 12 alternatives) and then all the ASCs (total 12, including one for midsize and excluding the base vehicle [Van]) were re-estimated by minimizing the sum of squared differences between the model-predicted and actual sales shares (as per *Ward's Automotive Yearbook* 2010) for each vehicle type. This process of adjusting ASCs is described in Train (2009). After this calibration process, ASCs corresponding to the six new hybrids (i.e., PHEVs and HEVs for SUV, Pickup, and Van body types) were added to this model. The differences in the ASCs of the new hybrids (PHEVs and HEVs corresponding to SUV, Pickup, and Van) and their ICE counterparts were restricted to equal the difference between the survey's existing hybrids (midsize PHEV and HEV) and midsize cars. Conditioned on this, the 18 ASCs (including the 12 from the previously described model and the 6 new vehicle types) were adjusted to match the predicted sales pattern (with corresponding hybrids included in the sales shares of SUVs, Pickups, and Vans) to the actual U.S. sales pattern in the base year. Table 4.3 provides these re-estimated ASCs for the final stage model (i.e., the original model plus the midsize car option new HEV and PHEV vehicle types). This final model with adjusted ASCs was used in the simulation for making predictions about the type of vehicle each synthetic household acquires in all future years where it is simulated to acquire a "new" vehicle (either through replacement or by adding a vehicle to its fleet). The modeling framework used here ignores the acquisition of "used" vehicles, but such opportunities can be added via a used-car option a topic (as assumed by Mohammadian and Miller [2003] or as modeled by Selby and Kockelman [2011]). Table 4.4 presents MNL parameter estimates for the SP vehicle-choice model based on the base-context conditions.

Table 4.3: ASCs Estimates for SP Vehicle Type Choice (Weighted MNL)

Variable	ASCs in the Original Model	Final Re-estimated ASCs
Subcompact	-0.9147	-0.4195
Compact	-1.210	-0.5770
Midsize	-	0.8695
Large	-1.165	-0.8044
Luxury	-0.4314	0.4305
Smart Car	-3.033	-2.735
HEV	-1.878	-1.519
PHEV	-0.4345	-0.0917
CUV	0.6566	0.8855
SUV	-1.452	-0.4299
SUV_HEV	-	-2.819
SUV_PHEV	-	-1.391
Pickup	-0.3442	-0.2429
Pickup_HEV	-	-2.632
Pickup_PHEV	-	-1.204
Van_HEV	-	-2.389
Van_PHEV	-	-0.9613
Hummer	-3.058	-2.721

Table 4.4: Parameter Estimates for SP Vehicle Type Choice (Weighted MNL)

Variable	**Coefficient**	**T-stat**
Fuel cost (dollars per mile)	-5.206	-2.77
Purchase price (dollars) x 10^{-5}	-4.004	-5.61
Male respondent x (Hummer, Pickup truck)	1.208	6.49
Male respondent x (Large car, Luxury car)	0.4621	2.92
Male respondent x SUV	0.3287	2.2
Age of respondent x (HEV, Subcompact, SUV)	0.01122	5.09
Household size x Smart Car	-0.5978	-4.63
Large household indicator (>4) x Compact	0.6849	3.02
Large household indicator (>4) x Hummer	2.240	5.71
Number of workers x PHEV	-1.097	-4.01
Number of workers x Pickup truck	0.3651	3.91
Number of household vehicles x (Compact, CUV, HEV, Large car, Luxury car, SUV)	0.2331	3.18
Household Income ($/Year) x Compact	1.03E-05	7.42
Household Income ($/Year) x SUV	4.15E-06	2.45
High income indicator (>$75k) x Luxury	0.3962	1.49
Income per member (dollars) x Pickup truck	6.02E-06	2.01
Job density (jobs per sq mile) x Compact	1.23E-04	4.14
Job density (jobs per sq mile) x Luxury car	7.20E-05	1.58
Household density (HHs per sq mile) x (PHEV, HEV)	1.40E-04	3.47
Log likelihood with constants only	-2351.08	
Log likelihood at convergence	-2342.75	
Pseudo R^2	0.1517	
Number of observations	1,098	

Coefficients on fuel cost and purchase price turned out to be statistically significant and intuitive, as expected. Results suggest that households with many vehicles are likely to select a CUV, HEV, large car, SUV, or a luxury car. Respondents from high-income households appear to prefer compacts, CUVs, HEVs, large cars, luxury cars, and SUVs, while those with higher incomes per household member are somewhat more likely to choose Smart Cars. Larger households are more likely to choose a compact car or Hummer and less likely to select a Smart Car, presumably due to seating-capacity considerations. Results also suggest that older respondents are more likely to choose an HEV, subcompact car, or SUV, with male respondents displaying more of a preference for Hummers, pickup trucks, large cars, luxury cars, and SUVs – relative to female respondents' selections.

4.4 VEHICLE USAGE AND GHG EMISSIONS ESTIMATES

In the national survey, each respondent was asked to report the average annual VMT of each vehicle in his/her household. These values are simply respondent estimates of a year's worth of mileage accumulation on each vehicle owned (rather than based on odometer readings, for example), and they generated low R-square values (for model fit) and counter-intuitive parameter estimates. Fortunately, there is superior national data for this key variable, so the vehicle usage model was estimated on the extensive 2009 National Household Travel Survey (NHTS) sample, with its 196,606 vehicles (and population expansion/sample correction factors). The NHTS sample reports a weighted average yearly VMT of 10,089 miles per vehicle (with σ = 9,244 miles). Table 4.5 presents the parameter and the elasticity estimates of the ordinary least-squares regression. The NHTS 2009 data set reports household density at the Census tract level, but the SSI data set only provide a ZIP code for location inference. Also, the NHTS dataset lack detailed fuel cost (dollars per mile) information. Thus, these two variables (household density and fuel cost) were not included in the model estimation. But these variables have important impacts on VMT and have been studied extensively in the past (see, for example, Haughton and Srakar [1996]; Greene et al. [1999]; Small and Dender [2007]; Hughes et al. [2008]; Fang [2008]; Brownstone and Golob [2009]; National Research Council [2009]; and Musti and Kockelman [2010]). Coefficients for variables of fuel cost and household density were added later (based on average of published elasticity estimates) to ensure more appropriate model sensitivities. The model's constant term was then adjusted to equate the average of predicted and observed VMT values.

Table 4.5: Annual VMT per NHTS 2009 Vehicle (Unweighted OLS)

Variable	Coefficient	T-Stat	Mean Elasticity
Constant	2.411	77.1	-
Pickup	-2.76E-02	-4.36	-
SUV	0.0987	14.92	-
Van	0.1108	12.02	-
Fuel cost (Dollars/mile)	-1.711	-	-0.250
HH density (#HHs/Sq mile)	-8.08E-05	-	-0.080
Household size	0.0644	28.12	0.168
Number of workers in household	0.2011	64.12	0.237
Number of vehicles in household	-0.1279	-60.53	-0.339
Age of vehicle (years)	-0.0636	-184.4	-0.568
Household income (dollars)	3.17E-06	43.00	0.221
R^2	0.2373		
Adjusted R^2	0.2373		
Number of observations	199,606		

Note: Dependent variable is Ln(VMT/1000). Elasticities were computed for each household and then averaged to provide mean sample elasticities.

Results are as expected, with vehicle age having a negative impact on annual VMT and exhibiting the greatest practical significance. Household income, size, number of workers, and number of vehicles also have statistically significant effects, but with lesser practical significance.

Table 4.5's parameters were used to predict annual VMT in the final year of simulation for each household in the year-2035 synthetic population (having grown to a total of 66,367 households). These VMTs were translated into GHG emissions using EPA's (2007) standard (well-to-wheels) conversion value (of 25.4 lb of CO_2e per gallon of gasoline) and EIA's (2002) 1.34 lb of CO_2e per kWh of electricity generated (U.S. average). The share of PHEV miles on electric power were estimated to be 0.43 using utility factor curves (as found in Markel and Simpson 2006; Gonder et al. 2009; Simpson 2006; Kromer and Haywood 2007). This is the average report for a PHEV with 30 mile all-electric range.

4.5 Summary

This chapter described the data set's acquisition and population correction, following by analysis of responses to various important survey questions and the behavioral models estimated (including calibration of ASCs to avoid stated-preference biases in vehicle acquisition). Though sample averages and responses under different scenarios can offer behavioral insights, it is the data-calibrated models that capture the multivariate nature of household behavior and provide the microsimulation framework to make predictions under a much wider variety of policy and pricing scenarios. The next chapter discusses how these calibrated models were applied to predict a variety of household decisions and simulate the long-run evolution of nation's vehicle fleet, as well as GHG emissions.

CHAPTER 5: RESULTS OF FLEET SIMULATION

This chapter presents the fleet modeling framework, details of scenarios tested, and simulation results. In applying the calibrated models described earlier, the microsimulation anticipates each household's vehicle holding (and use) decisions on a yearly basis, by relying on Monte Carlo draws (t allow for unobserved factors that add behavioral variability). The following section describes the modeling framework and the overall flow of vlaues between different sub-models.

5.1 DEMOGRAPHIC EVOLUTION

Demographic evolution of the synthetic 50,016-household population was carried out on a 2.66-Hz, 4-GB RAM personal computer and took 2 days to complete. The demographic evolution employs Monte Carlo techniques to apply models corresponding to marriage, divorce, child birth in-migration, and leaving home. The complete code for the demographic evolution and details of models used can be found in Tirumalachetty (2009) and Kumar (2008). Module corresponding to location choice model was dropped from the code because of lack of data and complexities involved. The number of households is predicted to grow by 32.7% over the 25-year simulation period, with population rising by 27% and household size falling by 4.07%. Average household income is expected to increase at a steady annual rate of 0.82%. These results are close to demographic trends observed via the U.S. National Household Travel Survey (Hu and Reuscher 2004). Vehicle fleet evolution simulation is carried out after demographic evolution, and involves application of calibrated models (transaction and vehicle choice) discussed in previous chapter. The MATLAB code for vehicle fleet evolution is provided in Appendix C. The next section discusses details of vehicle fleet evolution and scenario synthesis.

5.2 MODELING FRAMEWORK AND SCENARIO SYNTHESIS

The modeling framework in Figure 5.1 depicts the flow of control among different behavioral models underlying the microsimulation process. In the case of a "buy/acquire" decision, the SP vehicle choice model (with adjusted alternative-specific constants [ASCs]) was used to determine the type of vehicle acquired by the household. For "disposal" decisions, the household vehicle with the lowest systematic utility (based on the vehicle-choice model) was removed (to approximate this decision). "Replace" decisions relied on both these actions. In case of a "Do

Nothing" decision, current vehicle holdings of the household were retained. The following section describes the results of these models' applications in the simulation system.

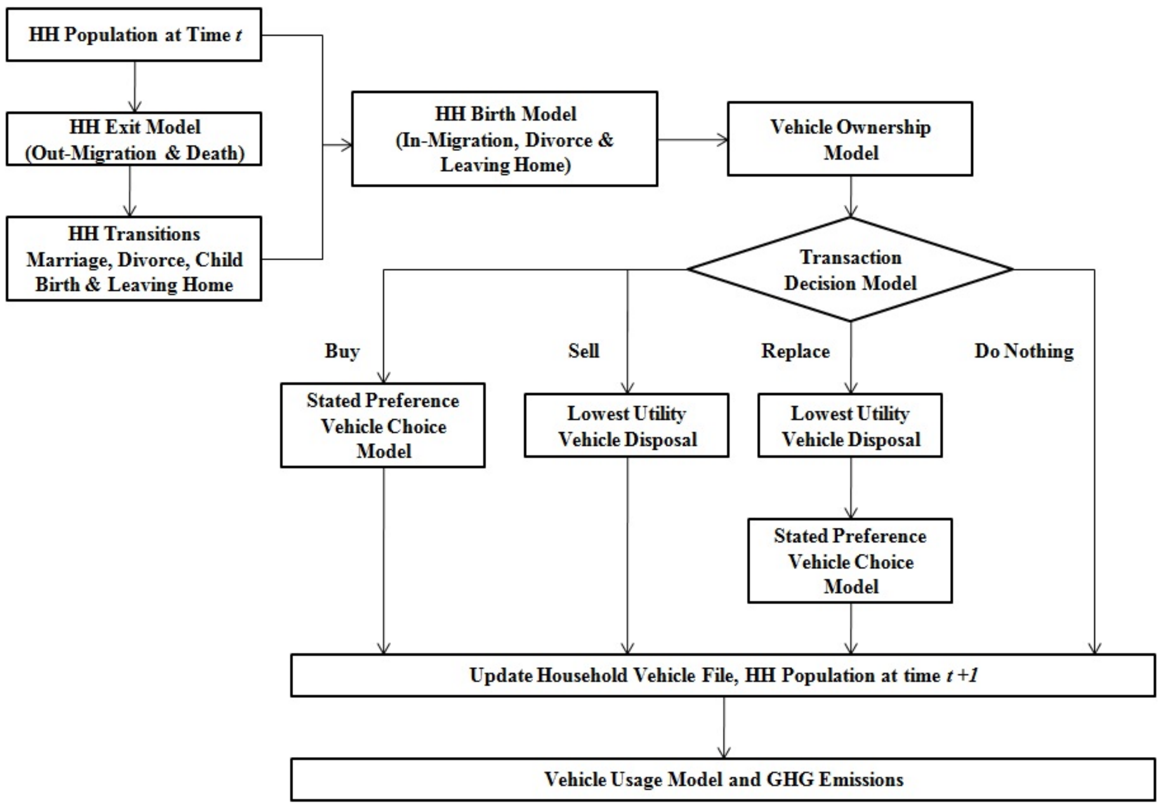

Figure 5.1: Modeling Framework for Microsimulation of Households and Fleet Evolution

Several scenarios, including higher gasoline prices, lower PHEV prices, feebate policies, and denser communities, were simulated. Under the TREND (or base-case) scenario, gasoline price was kept at $2.60 per gallon, PHEVs cost $8,000 more than their ICE counterparts, and household and job densities were fixed at the base year values throughout the simulation period. Other scenarios include a GASPRICE$7 scenario (where gas prices were raised to $7/gal), a LOWPRICE scenario (where the base price of the PHEV options fell by $4,100 for all body types), and a FEEBATE scenario (rebates to vehicles with over-30 mpg, and fees otherwise, at a rate of roughly $200 per mpg). They also include a stricter feebate scenario (FEEBATE2, with fees and rebate at a rate of roughly $400 per mpg, around the 30-mpg pivot point), and a HI-

DENSITY scenario (where all household and job densities were quadrupled), along with combinations of the FEEBATE scenarios with the LOWPRICE scenario and a GASPRICE$5 scenario.

Finally, a scenario based on the U.S.'s current policy of federal rebate for PEVs (ranging from $2,500 to $7,500, depending on battery size) was also tested. Based on the battery-size assumptions made for various PEVs in this study, all PHEVs (including that in SUV, Pickup, and Van body style) qualified for a $7,500 rebate. The next section presents the results of all these scenarios.

5.3 Fleet Composition, Vehicle Miles Travelled and GHG Emissions

Table 5.1 summarizes the fleet composition predictions for the final simulation year (2035) under different scenarios. The simulation does not remove aging vehicles unless households choose to let go of a vehicle. The average lifetime of a light-duty U.S. vehicle iis around 15years (Lu 2006), and the average age of such vehicles on the road is about 7 years. Here, the average vehicle age in the final simulation year (2035) was 6.7 years, under the TREND scenario – and thus very close to expectations. It should be noted that only "brand new" vehicles were available for purchases, but there is a market for used cars (see, e.g., Selby and Kockelman 2011), and therefore, age profiles can differ from that estimated here. These fleet shares in 2035 should represent long-run sales averages, since 25 years is enough to flush the whole fleet (although only 90% of the base year fleet replacement has been achieved here. Table 5.2 presents Year 2010 and 2035 VMT- and GHG-related emissions estimates across scenarios. NOx and VOC comprise 5 to 6% of total vehicle GHG (CO2e) emissions, while CO2 emissions account for the other 95 to 94% (EPA 2005). Newer vehicles in the household are expected to be driven more than the older vehicles, but this distinction is not been considered here.

Under the TREND scenario, the HEV market share was estimated to hit just 6.47% (including HEVs of all body types) by 2035, while the PHEV share (across all body types) came in at just 2.17%, and the Smart Car share stayed under 1% (at just 0.09%). U.S. household VMT is expected to rise by 65.4% vs. the 2010 base year.

Under the GASPRICE$7 scenario, market shares of HEVs, PHEVs, and Smart Cars rose to 12.3%, 3.78%, and 0.22%, respectively, as shares in Pickup trucks, SUVs, CUVs, and Vans fell. This scenario predicted the second highest market share (16.3% total) for PHEVs, HEVs, and Smart Cars across the nine scenarios examined here. It also resulted in the highest VMT and GHG emissions reductions (at 28.8% and 36.9%, respetively), as compared to TREND. The LOWPRICE scenario did not predict any significant fleet share changes vs. TREND, other than increasing the market shares of PHEVs slightly (to 2.54%, from 2.17% in the TREND scenario). Total VMT rose slightly under this scenario (just 0.56%) resulting in a slight increase in GHG emissions (0.23%).

Table 5.1: Vehicle Fleet Composition Predictions (Counts and Percentages) for the Year 2035

	Base Year - 2010		Base Scenario (TREND)		Low PHEV Price (LOWPRICE)		Feebate Policy (FEEBATE)		FeebateX2 Policy(FEEBATE2)	
Subcompact	6291	7.98%	5,456	4.45%	5,331	4.36%	5,619	4.57%	5,887	4.80%
Compact	13,115	16.64	30,384	24.77	30,029	24.53	30,936	25.17	31,006	25.28
Midsize	14,768	18.73	23,089	18.83	22,977	18.77	22,301	18.14	21,617	17.62
Large	3,437	4.36	2,104	1.72	2,251	1.84	2,156	1.75	2,166	1.77
Luxury	6,878	8.73	6,351	5.18	6,159	5.03	6,145	5.00	6,190	5.05
Smart Car	-	-	105	0.09	94	0.08	127	0.10	134	0.11
HEV	-	-	6,710	5.47	6,600	5.39	7,909	6.43	9,331	7.61
PHEV	-	-	2,256	1.84	2,658	2.17	2,627	2.14	3,057	2.49
CUV	3,936	4.99	8,452	6.89	8,396	6.86	8,469	6.89	8,008	6.53
SUV	12,273	15.57	13,573	11.07	13,514	11.04	13,361	10.87	12,875	10.50
SUV_HEV	-	-	274	0.22	307	0.25	290	0.24	263	0.21
SUV_PHEV	-	-	79	0.06	91	0.07	86	0.07	88	0.07
Pickup	11,524	14.62	17,827	14.54	17,949	14.66	16,871	13.72	16,029	13.07
Pickup_HEV	-	-	471	0.38	488	0.40	521	0.42	515	0.42
Pickup_PHEV	-	-	159	0.13	186	0.15	167	0.14	176	0.14
Van	6,607	8.38	4,636	3.78	4,608	3.76	4,618	3.76	4,607	3.76
Van_HEV	-	-	494	0.40	502	0.41	508	0.41	512	0.42
Van_PHEV	-	-	166	0.14	189	0.15	161	0.13	142	0.12
Hummer	-	-	62	0.05	68	0.06	56	0.05	63	0.05
Total #Vehs.	78,829		122,648		122,397		122,928		122,666	
Avg. #Vehicles per Household	1.59 Vehs/HH		1.85		1.85		1.86		1.86	

Note: These numbers are for the simulation's final-year synthetic population of 66,367 households (representing a total U.S. population of 534 million).

Table 5.1 (contd.): Vehicle Fleet Composition Predictions (Counts and Percentages) for the Year 2035

	Quadrupled Job & Household Densities (HI-DENSITY)		**Gas at $7/gal (GASPRICE$7)**		**Low PHEV Price + Gas at $5/gal**		**Feebate + Gas at $5/gal**		**Feebate2 + Gas at $5/gal**		**Federal Rebate**	
Subcompact	4,746	4.16%	8,686	7.09%	7,059	5.76%	7,584	6.20%	7,777	6.37%	29,788	4.40%
Compact	32,659	28.62	31,694	25.86	31,203	25.46	31,409	25.66	31,502	25.81	5,347	24.50
Midsize	19,217	16.84	21,447	17.50	22,324	18.21	21,374	17.46	20,394	16.71	2,163	18.57
Large	2,022	1.77	1,867	1.52	2,010	1.64	1,991	1.63	1,894	1.55	6,285	1.78
Luxury	6,031	5.29	5,232	4.27	5,622	4.59	5,307	4.34	5,376	4.41	90	5.17
Smart Car	89	0.08	273	0.22	139	0.11	177	0.14	192	0.16	6,462	0.07
HEV	7,478	6.55	13,097	10.68	9,765	7.97	11,487	9.39	13,437	11.01	2,948	5.31
PHEV	2,600	2.28	4,140	3.38	3,814	3.11	3,686	3.01	4,196	3.44	8,351	2.42
CUV	7,206	6.32	7,345	5.99	7,906	6.45	7,583	6.20	7,225	5.92	13,431	6.87
SUV	11,478	10.06	10,421	8.50	11,659	9.51	11,486	9.38	10,969	8.99	270	11.04
SUV_HEV	329	0.29	443	0.36	438	0.36	417	0.34	353	0.29	111	0.22
SUV_PHEV	117	0.10	104	0.08	91	0.07	105	0.09	88	0.07	17,690	0.09
Pickup	15,398	13.50	12,502	10.20	14,491	11.82	13,862	11.33	12,955	10.62	470	14.55
Pickup_HEV	611	0.54	713	0.58	683	0.56	713	0.58	681	0.56	203	0.39
Pickup_PHEV	190	0.17	191	0.16	190	0.16	156	0.13	165	0.14	4,644	0.17
Van	3,250	2.85	3,343	2.73	4,147	3.38	4,069	3.32	3,918	3.21	497	3.82
Van_HEV	479	0.42	837	0.68	733	0.60	741	0.61	701	0.57	203	0.41
Van_PHEV	144	0.13	194	0.16	227	0.19	185	0.15	160	0.13	78	0.17
Hummer	53	0.05	52	0.04	65	0.05	55	0.04	48	0.04	22,577	0.06
Total #Vehs.	114,097		122,581		122,566		122,387		122,031		121,608	
Avg. #Vehicles per Household	1.73		1.85		1.85		1.85		1.84		1.83	

Note: These numbers are for the simulation's final-year synthetic population, of 66,367 households (representing a total U.S. population of 534 million).

Table 5.2: VMT and CO2e Predictions (Total and per Vehicle) in 2035

	Base Year (2010)	Base Scenario (TREND)	Quadrupled Job & Household Densities (HI-DENSITY)	Low PHEV Price (LOWPRICE)	Feebate Policy (FEEBATE)	FeebateX2 Policy (FEEBATE2)
Total VMT (million miles)	1,210	1,979	1,628	1,990	1,998	2,007
% change from TREND			-17.74%	0.56%	0.96%	1.42%
Total CO_2e emissions (million pounds)	1,464	2,633	2,134	2,639	2,623	2,593
% change from TREND			-18.95%	0.23%	-0.34%	-1.52%

	Base Scenario (TREND)	Federal Rebate	Gas at $7/gal (GASPRICE$7)	Low PHEV Price + Gas at $5/gal	Feebate Policy + Gas at $5/gal	FeebateX2 Policy + Gas at $5/gal
Total VMT (million miles)	1,979	1,985	1,409	1,620	1,640	1,639
% change from TREND		0.30%	-28.80%	-18.14%	-17.12%	-17.18%
Total CO_2e emissions (million pounds)	2,633	2,625	1,661	2,018	2,014	1,976
% change from TREND		-0.30%	-36.92%	-23.36%	-23.51%	-24.95%

Note: These numbers are for the final year (2035) synthetic population, of 66,367 households

Both feebate scenarios prompted a shift toward more fuel-efficient vehicles, with the combined HEV/PHEV market share predicted to hit 9.98% (under the first FEEBATE scenario) and 11.48% (under FEEBATE2) by 2035. Market shares of Pickup Trucks and SUVs fell, while other shares moved negligibly. The two specific feebate policies examined here resulted in fee collections dramatically exceeding rebates, by a ratio of 4.5 (fees collected to rebates distributed) on average under the first FEEBATE scenario and by 3.5 under FEEBATE2, with 70% of rebates going toward HEV purchases on average. The ratio of fees to revenues is high, in part, because just three of the vehicle alternatives (the HEV, PHEV, and Smart Car alternatives) among the 12 total enjoyed fuel economy values above the policy's pivot-point threshold. The model also does not reflect technological improvements that may emerge over time, due to their great uncertainty; these include gas price changes, technology innovations, and regulatory shifts that can impact vehicle purchase and use prices, vehicle alternatives, and users' choices. Emissions under both these FEEBATE scenarios is expected to rise slightly (by 0.96% and 1.42%), thanks to lower vehicle operating costs. And, even though VMT is predicted to rise slightly under the two FEEBATE scenarios, the GHG emissions are predicted to fall slightly (0.34% and 1.52%), thanks to a higher share of HEVs and PHEVs in the fleet.

Inclusion of a $5/gal gas price assumption in the FEEBATE scenario increased the shift toward fuel-efficient vehicles, while $5/gal gasoline in the FEEBATE2 scenario resulted in the highest market share (16.37% total vehicles owned, in 2035) for all types of HEVs, PHEVs, and Smart Cars. As expected, the LOWPRICE scenario, along with a $5/gal gas price, increased the year-2035 share of PHEVs (from 2.17% in TREND to 3.53%). Emissions under all increased gas price scenarios are expected to fall, largely following the VMT trends.

Finally, the HI-DENSITY scenario simulated average vehicle ownership levels to fall to 1.72 vehicles per household (from 1.85 under TREND). Under this scenario, the share of compact cars, PHEVs, and HEVs increased noticeably, while those of CUVs, SUVs, and Pickup Trucks fell. Both total VMT and emissions are simulated to fall under the HIDENSITY scenario, due to relatively low vehicle ownership levels.

The $7,500 federal rebate scenario did not predict significant shifts in shares of PHEVs, as compared to TREND. Shares of PHEVs in all body types increased slightly, with the most significant shift occuring for the midsize body type (from 1.84% under TREND to 2.42%). A mild rebound effect is observed with this increase in PHEV shares, increasing the total VMT prediction by 0.30%,but still allowing emissions to fall slightly (by 0.30%), thanks to more electrified miles.

PHEV and HEV versions of SUVs, Pickups, and Vans attracted relatively few buyers during the simulations, making up small shares when compared to their conventional counterparts. Sales price is clearly a major factor, though gasoline sales can offset the up-front cost at many levels of fuel cost and driving distance (see, e.g., Tuttle and Kockelman 2011). There was not much variation across scenarios, with their average shares staying under 1 percent each – and ranging from 0.05% to 0.65%. HEV sales over the past 10 years have focused largely on the Toyota Prius (a midsize [and previously compact] car), and recent PEV releases and announcements favor midsize and compact cars (e.g., the Volt, Prius PHEV, Leaf, and Focus). Consumers exhibit a higher level of familiarity and experience with midsize HEVs and PHEVs, and their mpg numbers are striking (though actual gas savings is often not as significant as improving the fuel economies on lower-mpg body types).

This study did not consider the fall in price of these or other vehicles due to future technological advances and economies of scale in production. New CAFE legislation sets the target combined fuel economy of cars and light-duty trucks at 35 mpg by 2020 (EIA 2010) and may motivate auto manufacturers to pursue mild hybridization (rather than turning to true hybrids or PEVs). New technologies and fuel economy targets are certainly coming, so GHG emissions may fall much further than these simulations suggest, but it is not easy to predict how fleet shares will change.

To summarize, while 25 years is a long period of time, and generally enough to cycle through the nation’s personal-vehicle fleet almost entirely (thanks to an average light-duty-vehicle lifetime of roughly 15 years, according to NHTSA values [Lu 2006]), the various, relatively reasonable policy scenarios tested here appear to have relatively little impact on most vehicle sales and long-run ownership shares, with the exception of HEV purchases under all the gas-pricing scenarios and the stricter feebate scenario. More aggressive action appears needed if greater GHG reductions and lesser petroleum dependence are desired. It would also be interesting to recognize California's decision to allow eligible low-emission vehicles7 into that state's high-occupancy-vehicle (HOV) lanes, and localities plans' for preferential PEV parking spaces, though the analyst would have to guess at the systematic-utility impacts of such policies (and of BEV purchase), since these contexts or alternatives were not examined in the online survey's design.

5.4 Summary

This chapter presented the results of fleet simulation under different scenarios. Both gasoline pricing and feebate policy predicts a shift toward fuel-efficient vehicles but a stricter feebate policy with gasoline at $7/gal predicted the highest market for PHEVs, HEVs, and Smart Cars (jointly). A stricter feebate policy with gasoline at $5/gal follows the GASPRICE$7 scenario closely, in terms of vehicle type shares, but higher VMT overall, thanks to lower driving costs. Such policies need to be designed carefully, taking into account all possible impacts.

[7] Details of eligible vehicles can be found at http://www.arb.ca.gov/msprog/carpool/carpool.htm.

CHAPTER 6: CONCLUSIONS

This work presented a microsimulation framework to evolve a synthetic population's personal vehicle fleet in order to represent the U.S. population over a 25-year period (2010–2035). Data were collected via an online survey eliciting information on respondents' current vehicle holdings and use, purchase decisions, and intended vehicle choice under four different policy scenarios. Revealed and stated preference vehicle-choice models were estimated, along with transaction and use models.

Future market shares of PHEVs, HEVs, and vehicles like the Smart Cars are of interest to manufacturers, policy makers, and many others. Predicted shares vary by scenario, with 16.4% serving as their highest (total) predicted share by 2035, under the FEEBATE2 (and gas at $5/gal) scenario, with HEVs clearly dominating this share (with a predicted 12.4% share). While 16.4% is clearly higher than the TREND's 8.73% share of these three relatively efficient vehicle types, the GASPRICE$7 scenario's reductions in fleetwide CO2e emissions (36.9%) come mainly from lower VMT. Similar trends were also predicted for other gas-price scenarios.

The LOWPRICE scenario's results suggest a slight increase in the PHEV share (as compared with TREND), with almost no change in VMT and GHG emissions. Under both the FEEBATE policies, PHEV shares rise, but so does VMT (very slightly), owing to a rebound effect (see, e.g., Small and van Dender 2007), but CO2e emissions decrease, thanks to higher shares of fuel-efficient vehicles. Inclusion of a $7,500 federal rebate for modeled PHEVs resulted in a market share of just 2.85% for PHEVs, versus 3.78% with gasoline prices at $7 per gallon. Unfortunately, such numbers are far less than desired by policy makers and nations hoping to moderate climate change and other environmental implications of oil dependence, while addressing energy security, continuing trade deficits, high military costs, and other concerns (see, e.g., Greene 2010; Sioshanshi and Denholm 2008; Thompson et al. 2009).

While both the FEEBATE scenarios target purchases of fuel-efficient vehicles, the series of behavioral models used here suggests that a gas price of $7 per gallon will have more of an impact on ownership shares, as well as producing lower CO2e emissions, across scenarios. While both feebate policies do well in terms of promoting purchase of fuel-efficient vehicles, emissions reductions are not very promising due to a rebound effect. Joint implementation of feebate and gasoline pricing can help promote the purchase of fuel-efficient vehicles as well as tame the rebound effect by controlling driving costs. The FEEBATE2+GASPRICE$5 scenario predicted the highest market for HEVs, PHEVs, and Smart Cars jointly (among the nine scenarios evaulated), while resulting in a 25% GHG emissions reduction. While only a 29% population-weighted share of respondents expressed support for a feebate policy (vs. Austin's 63% [Musti and Kockelman 2010]), and only 35% (weighted) intend to buy a PHEV if it costs just $6,000 more than its convential counterparts (vs. Austin's 56%), greater support for such policies and more widespread use may emerge if (1) marketing is strategic and pronounced (e.g., alerting buyers to gasoline expenditures and external costs of their vehicle's emissions vs. alternative vehicles), (2) government incentives remain in place longer (e.g., the $7,500 PEV rebate endures past the first million large-battery PEV sales), (3) more PEV options emerge across vehicle types and manufacturers, (4) charging infrastructure is well advertised, (5) HOV-lane priorities and other perks are provided for PEV owners, (6) power pricing levels incentivize cost savings, and (7) battery prices fall, among other things. Perhaps feebate and such policies will trigger technological improvements that will then affect the vehicle mix (Bunch and Greene 2010). Whatever the future holds, this work helps anticipate how personal-vehicle ownership and usage patterns (and associated GHG emissions) may change under different policies and contexts. The methods and tools used in this study provide a framework for comparing various policy scenarios. This work also helps highlight the impacts of various directions in which consumers may head with such vehicles, and more scenarios may be tested.

In addition, it would be meaningful to microsimulate the used-car market (and its pricing dynamics), particularly since 40% (weighted) of survey respondents expected to buy a used car next (see, e.g., Selby and Kockelman [2011]). A model reflecting unexpected vehicle loss (due to thefts, malfunctions, and crashes) and delays in actual (vs. intended) acquisitions should also facilitate more realism. Estimation and application of simultaneous vehicle-choice-and-use models (as in Mannering and Winston 1985) may more directly link ownership and operating expenses. Finally, owners may exhibit greater variation in their vehicles' annual use, by vehicle type and in response to other attributes (observed and latent) than this study's model estimates suggest; and range-limited BEVs may shape VMT choices. Incorporating such details may improve VMT and CO_2e estimates. Of course, many such enhancements point to a need for further data collection, to better emerging vehicle make-and-model options, technologies, and traveler behaviors. The hope is that very solid markets exist, both in the U.S. and abroad, for energy- and carbon-saving vehicles, with smaller environmental and physical footprints. Models like those used here are one tool toward finding policies and vehicle designs that enable communities to better evaluate their options and achieve their aspirations.

PART II. WELFARE ANALYSIS OF CARBON TAXES AND CAPS

CHAPTER 7: BACKGROUND

7.1 INTRODUCTION

In the past few years, climate change has emerged as our planet's top issue. With impacts of climate change becoming increasingly visible, policy-level solutions to curtail emissions are becoming critical. Per-capita emissions in the U.S. are four times the world average (WRI 2009), and Congress has considered a number of proposals[8] aimed at abatement of greenhouse gases (GHGs). These proposals can be grouped into two main classes: emission (or carbon) taxes (on GHG producers) and an upstream cap-and-trade system on industries. This study makes use of various microeconomic methods to compare the GHG emissions and welfare impacts of emission taxes on consumer purchases to those same impacts from a household-level (downstream) cap-and-trade policy. The author's working paper, titled "The Welfare Implications of Carbon Taxes and Carbon Caps: A Look at U.S. Households" (Paul et al. 2010) summarizes much of this work. The following sections describe these policies, their impacts, and the various techniques used to evaluate such policies.

7.2 CARBON TAXES AND CAPS

Under an emissions tax, GHG producers (typically firms, who then pass taxes along to end consumers, as feasible) are taxed on the amount of GHG emitted; under a cap-and-trade system, a cap is set on the total amount of GHG that may be emitted by various industries, and unused allowances (credits) can be sold by firms. Emissions reductions by means of carbon taxes depend on the behavioral changes that follow price hikes from these taxes. A cap-and-trade policy, on the other hand, ensures a fixed reduction, with prices determined by trading dynamics in the carbon credits market.

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[8] These include the American Clean Energy and Security Act of 2009 (Waxman-Markey Bill) (http://www.govtrack.us/congress/bill.xpd?bill=h111-2454), the 2009 Kerry-Boxer Climate Bill (http://www.govtrack.us/congress/bill.xpd?bill=s111-1733), and Larson's Carbon Tax Legislation (http://www.larson.house.gov/index.php?option=com_content&task=view&id=852&Itemid=20)

Although both policies promise reductions, several issues need to be resolved to achieve political acceptability. Both policies will result in an effective price on GHGs that is ultimately borne (at least to a large extent) by end consumers. An important question is how these costs will fall across households of different income classes and across regions. Such policies can be evaluated based on three criteria: cost efficiency, uncertainty of results, and distributional (incidence) effects (Aldy et al. 2008). Various studies have evaluated carbon taxes and caps for achieving targets, with special consideration of distributional effects (of benefits and burdens) using different techniques.

Regressivity arises when a policy imposes a greater burden on the relatively poor than on the relatively well to do. Wier et al. (2005) investigated the social impacts of the Danish CO_2 tax, examining its direct and indirect impacts on industries and households. Their results suggest regressivity in tax payments relative to household income for both direct taxes (applied directly on consumers) and indirect taxes (as applied to industries upstream). Direct taxes were found to be more regressive than indirect taxes. Weather distinctions across regions require different heating and cooling needs, and power generation relies on different feedstocks. These differences cause carbon policies' impacts to vary across regions, and few studies have considered such variations. Wier et al. (2005) observed regressivity over space, with urban neighborhoods carrying fewer burdens, since urban homes generally have less heating and travel distance needs, ceteris paribus. An understanding of the regional variation of these effects will provide important inputs for tax policy design.

Brannlund and Nordstrom (2004) analyzed the impacts of Sweden's energy and environmental policy in terms of consumer response and welfare effects. Two scenarios were considered: the first involved a 100% increase in the CO_2 tax, while the second relied on a revenue-neutral tax reform that doubled the CO_2 tax and returned revenues in the form of reduced Value-Added Tax (VAT) rates for public transportation. They found the CO_2 taxes to be regressive (with low-income households experiencing a larger share of taxes per SEK[9] of income), with the effective percentage increase in tax payments for low-income households about 4% more than for higher-income households. They found their second scenario also uneven in terms of welfare

[9] Swedish Krona.

distribution, with urban areas receiving a net subsidy, and those in non-urban areas paying a net tax (primarily due to longer driving distances and lesser transit access in rural areas).

Grainger and Kolstad (2009) used 2003 Consumer Expenditure Survey (CES) data and emissions estimates from an input-output (I-O) model to estimate the distributional effects of a GHG tax or cap in the U.S. context. They estimated the ratio of energy-intensive expenditure to annual household income for the lowest income group to be 8 times higher than that of the highest income group. This ratio is 2.9 times higher if lifetime income is used. They also estimated that carbon taxes are more regressive on a per-capita basis than on a household basis. Hasset et al. (2009) estimated the direct (fuel consumption) and indirect (other goods) incidence of a carbon tax at a household level. These effects were evaluated using annual and lifetime measures of income for groups of households, assuming all tax burdens are borne by consumers (rather than producers). They also found the direct component of the carbon tax to be more regressive than the indirect component. Shammin and Bullard (2009) estimated the household-level incidence of carbon taxes or allowance costs (carbon credit costs). Their results confirm conclusions of previous studies that both carbon taxes and cap-and-trade policies are regressive. For a hypothetical carbon tax of $100 per (metric) tonne, they estimated the lowest-income quintiles to experience a price rise of up to 5% of their income compared with 2% or less for higher-income households.

An upstream implementation of a cap-and-trade policy does not leave much scope for behavioral change since it impacts consumers similarly to carbon taxes (in the form of increased prices). An investigation of downstream implementation illuminates the role of behavioral changes and emissions reductions. Roberts and Thumim (2006) discussed various carbon-trading schemes, looking specifically at the issues involved in downstream vs. upstream cap-and-trade systems. The analysis presented in this report compares the economic impacts of carbon taxes and a cap-and-trade system (with caps falling downstream, on households).

The regressive effects of carbon taxes and cap-and-trade systems seem certain, relative to the status quo. Different strategies have been proposed to counter such effects. Kerkhof et al. (2008)

examined the impacts of a comprehensive tax that covers all six GHGs[10] of the Kyoto Protocol. They estimated the distributional effects of these comprehensive taxes using I-O analysis and data on U.S. consumer expenditures. Their results suggest that this comprehensive tax reduces the regressivity of the tax burdens on income groups as compared to a CO_2-only tax. Under a CO_2 tax, low-income deciles were estimated to pay about 3% more of their income as taxes, when compared to higher-income households; under a comprehensive tax this difference was estimated to be around 2%.

Dinan and Rogers (2002) examined the ways in which carbon credits can be allocated and ways in which the revenues generated by different allocation schemes can be used, as well as how these decisions impact the distributional effects of an allowance-trading policy. Metcalf (1999) estimated the distributional impacts of an environmental tax with annual and lifetime income levels being used to group households. He suggests that the distributional effects of an environmental tax can be tackled by returning tax revenues using income tax rebates. Shammin and Bullard (2009) illustrated that regressive effects can be offset by either reducing other taxes or distributing the revenues equally among households on a per-household or per-capita basis. The latter policy will not cover the costs for high-income households but will cover the costs for some lower-income households. For high-income households, this should induce behavioral shifts to energy-efficient lifestyles. If rebates were to be distributed on a per-capita basis, then larger low-income households are expected to benefit the most, with smaller, high-income households bearing more costs.

7.3 Policy Impacts Evaluation

As discussed above, multiple policy outcomes – like meeting GHG reduction targets, distributional effects, and costs to achieve policy targets – are key criteria for policy evaluation. The accuracy of any analysis depends on the methods used and related assumptions. In the past, various microeconomic techniques have been used to evaluate impacts. These techniques range from basic econometric models for supply and demand to complex models simulating the national economy. For example, Brannlund and Nordstrom (2004) formulated and estimated an

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[10] These gases are carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydroflourocarbons, and perfluorocarbons.

econometric model (Quadratic Almost Ideal Demand System [QAIDS]) for non-durable consumer demand in Sweden that utilizes micro and macro data. In the first stage, the household determines spending levels on durable and non-durable goods. In the second stage, the household allocates expenditures among commodities within these nests. The authors ran simulations under different scenarios based on empirical models estimated from the Swedish Household Expenditure data and estimated that the CO_2 tax had regional distribution effects (with sparsely populated areas carrying a larger share of tax burdens).

The use of I-O models (Miller and Blair 1985) is widespread in the area of tax policy evaluation. Fullerton (1995) used an I-O model to estimate how U.S. environmental taxes pass from taxed industries to all other industries. His results suggest that enforcement costs are higher than the tax revenue if there are separate taxes for each industry. Metcalf (1999) employed a 40-sector I-O model to estimate the impact of environmental taxes and estimated that regressivity of this tax system can be reduced by giving households payroll and personal income tax rebates.

Fullerton (1995) and Metcalf (1999) explained in their appendices how I-O accounts can be used to trace price changes resulting from economy-wide taxes. Two of the most important assumptions of the model are as follows (Metcalf [1999], page 22):

(1) Goods are produced and sold in a perfectly competitive environment such that all factor price increases are passed forward to consumers, and
(2) Input coefficients (the amount of industry *i* used in production of industry *j*) are constant.
The set of equations relating to the value of all inputs and the value added to the value of outputs can be expressed in matrix notation as follows:

$$(I - A')P_1 = V \qquad (7.1)$$

where P_1 is a vector of industry prices, p_i, and V is a vector whose i^{th} element is $\frac{v_i}{x_i}$. v_i is the value added in industry *i,* and x_i is the total output of industry *i.* This gives:

$$P_1 = (I - A')^{-1}V \qquad (7.2)$$

The price vector P_1 thus changes as taxes are added to the system and becomes:

$$P_1 = (I - B')^{-1}V \qquad (7.3)$$

where B is an N x N matrix with elements $(1 + t_{ij})a_{ij}$, and t_{ij} is the tax rate for use of inputs from industry i by industry j. Tax rates can thus be computed as the ratio of the required tax revenue from the industry divided by the value of output from that industry, as follows:

$$t_i = \frac{\alpha_i R}{\sum_{j=1}^{N} x_{ij}} \qquad (7.4)$$

Next step is to allocate these price changes to consumer goods. The Personal Consumption Expenditure (PCE) bridge tables provide information on how much of each consumer good is produced in each industry, represented by the Z matrix, and the vector of consumer goods prices can be given as $P_C = Z'P_1$.

Various studies have used Fullerton's (1995) and Metcalf's (1999) I-O techniques. Wier et al. (2005) used a static I-O matrix and a tax matrix and combined I-O analysis with household characteristics. They used national I-O tables to estimate indirect tax payments by households for different commodities based on direct tax payments by industries. Shammin and Bullard (2009) used a detailed data set based on a 491-sector I-O model and about 600 categories of consumer expenditure to estimate the household-level incidence of carbon taxes or allowance costs. They estimated total energy-related carbon emissions of U.S. households for 2003 by multiplying household expenditures (in dollars) by appropriate carbon intensities (pounds per dollar). Household expenditures were obtained from the CEX for 2003. They estimated carbon intensities based on the 1997 Economic Input-Output Life Cycle Analysis (EIOLCA) developed by researchers at Carnegie Mellon University (GDI 2008).

Grainger and Kolstad (2009) examined consumption patterns of different income groups to estimate the regressivity of carbon taxes. They believe that an upstream cap-and-trade program will result in similar outcomes via a different mechanism, so they focused only on the tax policy's results. They examined the effect of a $15/ton CO_2 price and used CES data for details on household consumption patterns. Using the U.S. Bureau of Economic Analysis's (BEA's) I-O tables, they translated the final demand of each industrial sector into sector-level production and intermediate demands. Finally, they used the same technique to calculate the price of final consumption in a sector due to taxes on direct carbon emissions. Their I-O model can be formulated as follows:

$$x = (I - A)^{-1}c \qquad (7.5)$$

where x is a vector of total outputs across sectors, c is a vector of final demands for each sector's output, and A is a matrix of technical coefficients (essentially expenditure shares for each dollar of output, sector by sector). The resulting total emissions are then given by

$$e = g'x = g'(I - A)^{-1}c \qquad (7.6)$$

where g is a vector of emissions factors. This vector was obtained from Carnegie Mellon University's version of the U.S. I-O model (GDI 2008) to obtain the amount of CO2e emissions associated with each sector. Thus, a tax of T dollars per ton of CO_2e will result in a total tax of Te dollars per dollar of output across sectors. Grainger and Kolstad (2009) then matched I-O model categories to a PCE category. In this way, the amount paid by an average consumer in each income group can be determined for a given tax level.

Hasset et al. (2009) estimated the effects of a \$15 tax per metric ton of CO_2 on U.S. consumers in 1987, 1997, and 2003. They used the BEA's Make and Use tables to derive an industry-by-industry transaction matrix. Using techniques described by Fullerton (1995) and Metcalf (1999), they calculate the taxes paid by each household. They estimated that carbon taxes are more regressive when annual income is used as a measure of economic welfare than when lifetime income measures are used.

Even though I-O models are based on assumptions like perfectly competitive environment (all price increases passed to consumers) and fixed coefficients (input substitution not allowed as factor price change), they provide a straightforward technique to back-calculate the effect of taxes rippling through an economy. Tax ripple effects can differ greatly from the direct impact of taxes at a consumer level (e.g., Grainger and Kolstad [2009]). I-O models (to estimate price changes under tax policies) can be combined with behavioral models, such as a translog utility model (e.g., Tirumalachetty and Kockelman [2010]), to estimate impacts more flexibly.

7.4 Summary

This chapter describes two policy solutions for reducing GHG emissions: carbon taxes and carbon caps. Regressivity is an important dimension for evaluating the impacts of such policies, and many studies (e.g., Hasset et al. 2009; Grainger and Kolstad 2009; and Shammin and Bullard 2009) have used I-O models to examine the impacts of higher energy and carbon taxes on households, by assuming that all price increases will be passed on to the consumers and expenditure shares are constant (substantially limiting substitution opportunities among factor inputs). In reality, equilibrium price shifts and declining marginal rates of substitution affect choice, so only a portion of price shifts will be passed on to the consumers unless the markets are perfectly competitive in production or the demands are perfectly inelastic. Shammin and Bullard (2009) suggested that lack of data on price elasticity is one reason behind disallowing substitution. These studies do not allow for flexible substitution patterns by consumers and assume homogeneity in good types by expenditure category. In reality, there are great variations in the energy requirements of different products within a single category of consumption – like beef versus beans, and large SUVs versus hybrid vehicles. Information on household's substitution behaviors can be critical for evaluating policy impacts. Policies like vehicle feebates (see, e.g., Train et al. [1997] and Greene et al. [2005]) encourage consumers to adopt energy-efficient vehicles, and anticipation of the effects of simultaneous introduction of such policies will be helpful in evaluating potential regressivity. In spite of these issues, existing studies provide the necessary foundation for studying the impacts of carbon taxes and cap-and-trade systems. The next chapter gives an overview of the data sets and microeconomic methods used in this study.

CHAPTER 8: DATA DESCRIPTION AND METHODOLOGY

The data sets used in this study come from various sources, and range from details of annual household expenditures to accounts of inter-industry transactions in the U.S. economy. They have been used to estimate and apply different microeconomic models, and this chapter describes how these models connect to address the objectives of this work.

8.1 DATA DESCRIPTION

The data on demographics and household expenditures come from the national-level Consumer Expenditure (CEX) Survey conducted by the U.S. Census Bureau for the Bureau of Labor Statistics (BLS). The year 2002 CEX data are for 4,472 households and were obtained from the National Bureau of Economic Research (NBER). Besides providing demographic characteristics, the data list each household's annual spending across NBER's 109 categories of expenditure. These categories have been aggregated here into 8 expenditure categories, as follows: Natural Gas, Electricity, Air Travel, Public Transport, Gasoline, Food, Other Expenditures, and Household Savings. Household Savings were computed by subtracting each household's total expenditures from its total income, and zero savings were assigned in cases of negative savings (with income adjusted to equal expenditures). Table 8.1 presents the summary statistics (population-weighted) of household expenditures across the 8 aggregated consumer goods categories and as shares of household expenditures.

The CEX data do not contain information on prices of these consumer goods categories, so price estimates were obtained from other sources. Air Travel prices come from the U.S. Department of Transportation (DOT 2003), Public Transport prices come from the National Transit Database (NTD 2003), while price data for Electricity, Natural gas, Gasoline, and Food Categories comes from the BLS (www.bls.gov). Savings and Other Expenditure categories are assumed to have a unitary price (i.e., one dollar per unit). Consumer Price Indices (CPIs) are used as proxies for the prices across both food consumption categories. Appendix D summarizes these price assumptions.

Table 8.1: Summary Statistics of 2002 U.S. Consumer Expenditure Survey Data

Variable	Mean	Std. Dev.	Min	Max
Expenditures ($)	45,705	38,436	3,359	604,931
Savings ($)	15,224	28,780	0	530,042
Other Expens. ($)	22,150	17,049	772	333,674
Natural Gas ($)	345.1	453.2	0.0	3,984
Electricity ($)	1,011	654.3	0.0	7,092
Air Travel ($)	258.4	679.8	0.0	11,600
Public Transport ($)	144.9	583.8	0.0	24,955
Gasoline ($)	1,299	980.9	0.0	10,704
Food ($)	5,466	3,298	0.0	58,094
Percentage (%) of Total Household Expenditures				
Savings	23.33	24.91	0.0	96.77
Other Expens.	53.79	21.36	0.019	99.90
Natural Gas	1.02	1.65	0.0	18.01
Electricity	3.09	2.74	0.0	32.89
Air Travel	0.52	1.40	0.0	27.40
Public Transport	0.36	1.19	0.0	33.87
Gasoline	3.33	2.46	0.0	22.66
Food	15.93	8.77	0.0	64.32

The CEX data report the number of vehicles owned by each household but do not reveal the types of vehicles held. Therefore, vehicle types held by each household were determined using the stated preference vehicle choice models presented in Tables 4.3 and 4.4, employing Monte-Carlo techniques. The type of vehicle determines the purchase price and fuel economy of each vehicle held by the household. A separate vehicle expenses (Vehicle Expens.) category was created after assuming that one-eighth (12.5%) of the retail price of all vehicles owned by the household was counted in each year of the CEX data. The average of these annual prices (across all vehicles held by each household) defined the price for this expense category (for each household, separately), and this price times the number of household vehicles equals the total expenditure assigned to the Vehicle Expens. category.

Savings and Other Expens. categories were adjusted to accommodate these vehicle expenditures. First, all vehicle related expenses (e.g., maintenance, principal and interest payments on vehicle loans) from the Other Expens. category were included in the Vehicle Expens. category. If the estimated one-eighth of retail price exceeded the vehicle-related expenses, proportionate amounts were taken from the Other Expens. and Savings categories, though neither was allowed to go below $1,000 and $100, respectively. Only in very few cases (<1%), household income was increased in order to accommodate a relatively high simulated Vehicle Expens. category. The CEX dataset reports the number of vehicles held by the household (with non-integers value for many households – suggesting shorter periods than 1 year of ownership for some vehicles), and this defined the units of the Vehicle Expens. Category. The average fuel economy of each household's fleet was used to convert the expenditure on gasoline (in gallons) to vehicle usage (in miles). Also, average fuel economy was used to convert the gasoline price from dollars per gallon to dollars per mile, for each household.

The resulting 9 category household expenditure values were then used for microeconomic analysis, as described below.

8.2 MICROECONOMIC METHODS

This work makes use of different microeconomic methods to evaluate the impacts of carbon taxes and a downstream cap-and-trade system. Founded on the principles of consumer demand theory, this work also incorporates an I-O model to gauge the impact of inter-industry transactions on final prices of consumer goods under the effect of climate policies. The following sub-sections give an overview of these microeconomic methods and how they weave together to create a system of models for behavioral forecasting.

8.2.1 Consumer Demand Theory and the Translog Utility Function

Consumer demand theory deals with consumer behavior and consumption decisions. Standard assumptions of rational behavior imply that consumers choose bundles of goods that maximize their latent utility. Application of this fundamental principle requires utility specifications to be flexible enough to reasonably approximate consumer behaviors. Theoretical restrictions on utility specifications are homogeneity (pure inflation), summability (expenditures total to income), and symmetry of price derivatives of compensated demand (see, e.g., Varian [1992]). Christensen et al.'s (1975) transcendental logarithmic (translog) specification and Deaton and

Muellauer's (1980) Almost Ideal Demand System (AIDS) offer such opportunities. Here, Christensen et al.'s (1975) translog specification is used to represent direct utility, as follows:

$$-\ln U(X) = \alpha + \sum_i \alpha_i \ln X_i + 0.5 * \sum_i \sum_j \beta_{ij} lnX_i lnX_j \ . \qquad (8.1)$$

where U denotes household utility, the X_i denote consumption levels of each goods category i, and the α and β's are parameters to be estimated. Utility maximization involves estimation of demand quantities subject to budget constraints (Varian 1992) as follows:

$$\max u(X) \ subject\ to\ p\,X \leq M \ , \qquad (8.2)$$

where $u(X)$ is a direct utility function, X is the vector of consumption goods, p is a vector of associated prices, and M is the household's budget or annual income. Under a cap-and-trade policy, consumers are subject to an additional GHG-emissions budget. In this case, the utility maximization problem is formulated as:

$$\max u(X) \ subject\ to\ p\,X \leq M\ and\ cX \leq B \ , \qquad (8.3)$$

where c is a vector of GHG emission rates for each expenditure category, and B is the carbon budget or cap on each household.

Under a cap-and-trade system, households are allowed to sell extra GHG credits and buy credits at the same market-determined or otherwise-determined price. In this study, the price of carbon credits is assumed to be pre-determined (at \$50 and \$100 per ton of CO2e). Buying of carbon credits will increase the carbon but will decrease the monetary budget, and vice versa when carbon credits are sold.

Under a single income constraint, Equation (7.1) yields the following expenditure share equations (Christensen et al. 1975):

$$\frac{p_j X_j}{M} = \frac{\alpha_j + \sum \beta_{ij} lnX_i}{\alpha_M + \sum \beta_M lnX_i} \qquad (8.4)$$

where $\alpha_M = \sum \alpha_K$ and $\beta_M = \sum \beta_{ik}$. Summability is ensured by the following normalization: $\sum \alpha_k = 1$. These expenditure share equations were estimated using STATA's non-linear, seemingly unrelated regression routine with constraints for parameter consistency, resulting in a simultaneous equation system (SES) specification. Estimation results are presented in Section 7.3.

Evaluating the welfare impacts of government policies is a meaningful way to compare such policies. Equivalent variation (EV) provides the equivalent change in income that would be required for achieving the same level of (maximized) utility that occurs due to modeled changes in a consumer's environment (see, e.g, Varian [1992]).Computation of EV requires an indirect utility specification (i.e, the maximized utility function, given prices and budget constraints). Obtaining a tractable expression for indirect utility under a translog direct-utility specification is complex (if not impossible), so this study maximizes the utility of all CEX households under different budget constraints to equate the pre- and post-policy utility levels for each household, thereby inferring the EV value of the policy, for each household separately.

8.2.2 Carbon Taxes and Carbon Caps

Climate policies involving pricing and/or capping need to be designed very carefully. Low tax rates (or high caps) may not motivate significant behavioral shifts, while higher rates (or lower caps) may excessively burden the low-income (or high-consuming) households. Earlier studies suggest a wide range of GHG-emissions costs. Tol's (2005) assessment of 103 published estimates of marginal costs of CO_2e production yielded an average of \$12.40/ton. The Intergovernmental Panel on Climate Change's (IPCC 2007) Working Group II survey of 100 estimates suggests a \$3 to \$95 range (per ton of CO2e). In order to stabilize GHG emissions, prices are expected to be \$25 to \$70 per ton by 2020, rising to \$127 to \$130 by 2050 (Clarke et al. 2007). In this study, to motivate reasonable behavioral shifts, \$50- and \$100-per-ton taxes were imposed, to anticipate welfare implications across household classes.

Carbon caps were set at 10 and 15 tons per person per year. Households are allowed to sell excess credits (often the situation of lower-income and/or larger households), effectively increasing their income. The price for buying or selling extra credits was set at \$50 and \$100/ton, resulting in Table 8.2's four cap-and-trade scenarios. These cap-and-trade situations have been taken from Tirumalachetty and Kockelman (2010) who aimed to roughly approximate the carbon emissions (per capita) under the carbon taxes. In reality, the trading price for carbon credits may be determined by market forces of demand and supply, but here it is assumed to be pre-determined.

Table 8.2: Cap-and-Trade Scenarios

	Cap on Emissions (tons/person/year)	Fixed Rate for Trading ($/ton)
Scenario1	10	50
Scenario2	10	100
Scenario3	15	50
Scenario4	15	100

In forecasting future expenditure shares, a household's direct utility equation was maximized with increased prices and the standard budget constraint. Under the cap-and-trade scenario, utility was maximized subject to both carbon and money budget constraints. Increased prices for each expenditure category were determined by application of the I-O model, as described here now.

8.2.3 Input-Output Model for Taxation Calculations

I-O analysis was used to illustrate and anticipate the effects of carbon taxes on goods prices, since prices ultimately depend on a chain of more expensive inputs (due to emissions taxes applied throughout the production stream). The need to estimate goods price ripple through economy suggest the use of an I-O model.

I-O tables were constructed using the BEA's 2003 make and use table, across 418 sectors. Hasset et al.'s (2009) methodology was used to estimate the effect of an economy-wide CO2e tax on price of different consumer goods. As discussed in Section 6.2 of this report, the new price vector under carbon taxes was computed using Eq. 6.5. The main challenge here is to get the inter-industry tax rates. Since emissions data are not readily available for the 418 sectors included in the analysis, emission estimates from Carnegie Mellon University's Green Design Institute's (CMUGDI) EIO-LCA model (as described by Grainger and Kolstad [2009]) were used for year 2002 inter-industry data (CMUGDI 2010). The model was run for each of the 418 sectors, one at a time to obtain estimates of CO_2e emissions (in tons) resulting from $1 million worth of output from that sector (thereby reflecting both direct and indirect emissions). The estimated price increases in the 418 sectors as a result of economy-wide carbon taxes ($50 and $100/ton) were then transferred to the 9 expenditure categories of the CES sample by means of a Personal Consumption Expenditure (PCE) bridge table.

Appendix E's Table E1 presents the estimated price increases for each of the 418 sectors, and Table 8.3 presents the top-ten sectors in terms of CO_2e emissions per dollar worth of product. It is interesting that cement manufacturing tops the list, with cement being a major component of transportation structures.

Table 8.3: Top-Ten Industry Sectors for Carbon Emissions (per $1 M Output)

Sector	GHG Emitted (Tons/$1M)
Cement manufacturing	11,600
Electric power generation, T & D	9,370
Cattle ranching and farming	7,750
Fertilizer manufacturing	6,620
Industrial gas manufacturing	5,510
Lime and gypsum product manufacturing	5,320
Grain farming	4,470
Pipeline transportation	4,400
Cotton farming	4,290
Dairy cattle and milk production	4,260
Coal mining	4,240

The price increases associated with six of the nine aggregate expenditure sectors is shown in Table 8.4, for both tax policies ($50 and $100 per ton of CO2e).

Table 8.4 Percentages: Price Increases Triggered by Carbon Taxes

Sector	Base Prices ($ per unit)		Carbon Emission Assumptions (lbs per unit)		Carbon Price	
					$50/ton	$100/ton
Natural Gas	$8.11	1000 cuft	120	1000 cuft	45.2%	91.4%
Electricity	0.096	kWh	1.3	kWh	46.9%	93.7%
Air Transport	0.17	Mile	0.934	Mile	9.9%	19.8%
Public Transport	0.03	Mile	0.3	Mile	9.4%	18.7%
Gasoline	1.51	Gallon	19.56	Gallon	43.9%	99.1%
Food	1	Unit	1	Unit	7.8%	15.6%
Savings	1	Unit	0	Unit	0.4%	0.8%
Other Expens.	1	Unit	0	Unit	1.9%	3.8%

Of course, there is also the Vehicle Expens. category (the ninth good type), whose price increase is assumed to be reflected by the change in consumer surplus (estimated using Tables 4.3 and 4.4's vehicle choice model). The types of vehicles held by each household were determined under both carbon tax situations using Monte Carlo techniques (as described in Section 7.1). New prices under the two carbon tax scenarios can be determined using the Section 7.1's procedure. But under this method, prices can be estimated to decrease, since consumers might choose less-costly, more fuel-efficient options. Generally, prices of all goods are expected to increase under carbon taxes, so a consumer surplus-based methodology was adopted to estimate the vehicle category's price increase. The change in consumer surplus is measured as the normalized difference in the before and after expected maximum utility levels (the logsums, in the case of multinomial logit (MNL) models). The change in expected maximum utility can be expressed by the following logsum formula:

$$E\left(Max(U_{in}^{1}) - Max(U_{in}^{0})\right) = E\left(Max(U_{in}^{1})\right) - E\left(Max(U_{in}^{0})\right) \quad (8.5)$$

$$= ln\sum_i e^{V_{in}^{1}} - ln\sum_i e^{V_{in}^{0}} \quad (8.6)$$

where n denotes the household and i denotes the vehicle type. These logsums were computed for each household using the stated preference (SP) vehicle choice model presented in Tables 4.3 and 4.4. This difference in logsum values was normalized by the marginal utility of money (in this case, the parameter estimate corresponding to vehicle price, since it is units of utils per dollar) to estimate the monetary impact of each policy's consequences. These estimated changes in consumer surplus were added to the base vehicle prices (described in Section 7.1) to obtain the annual vehicle expenses for each household, under each carbon pricing scenario. Average fuel economy for each household was computed as the average across all vehicle types held by the household (for both carbon tax situations). This estimated average fuel economy was used to compute each assigned vehicle's usage price (in dollars per mile) based on the gasoline price (dollars per gallon), as obtained from the I-O analysis in the case of carbon taxes.

8.3 Estimation

As described in Section 7.2.1, translog demand equations were estimated using STATA's SUR routine, and the results are presented in Table 8.5. Only 8 out of 9 expenditure shares equations were used in the estimation process, since summability ensures results for the 9th equation.

Table 8.5: Parameter Estimates for Translog Demand Equations (9 categories overall, using SUR regression)

	Natural Gas	Electricity	Air Travel	Public Transport	Vehicle Usage	Food	Savings	Other Expens.	Vehicle Expens.
α_{ij}	-0.06	-0.121	-0.028	-0.017	-0.069	-0.014	-0.139	0.019	-0.57
β_{ij} Values (x 10^{-3})									
Natural Gas	-1.23	0.582	0.059	0.053	0.361	1	0.021	2.714	0.732
Electricity	0.582	-3.832	0.124	0.126	0.62	4.38	-0.05	7.255	2.313
Air Travel	0.059	0.124	-1.132	-0.027	0.031	0.596	0.019	0.727	0.296
Public Transport	0.053	0.126	-0.027	-0.64	0.385	0.447	0.007	0.317	0.334
Vehicle Usage	0.361	0.62	0.031	0.385	-6.184	4.375	-0.153	3.992	2.476
Food	1	4.38	0.596	0.447	4.375	-64.45	0.225	29.26	10.78
Savings	0.021	-0.05	0.019	0.007	-0.153	0.225	-20.07	0.728	-0.253
Other Expens.	2.714	7.255	0.727	0.317	3.992	29.26	0.728	-90.88	36.01
Vehicle Expens.	0.732	2.313	0.296	0.334	2.476	10.78	-0.253	36.01	-6.937
R^2	0.576	0.766	0.467	0.282	0.776	0.896	0.702	N/A	0.862

All equations except the ones corresponding to Air Travel and Public Transport (which are relatively rare expenditures for Americans, with wide swings in consumption) enjoy reasonable fit. Table 8.5's parameter estimates were used to estimate expenditure shares of each household, under each carbon tax and cap-and-trade scenario.

Each household's translog utility function (based on Table 8.5's 90 parameter estimates) was maximized under the corresponding prices and budget using MATLAB's constrained optimization routine. Under carbon taxes, households faced only an income budget with increased prices, while under cap-and-trade they also faced a second, CO2e-emissions budget. After this first optimization, households under the cap and trade setups were allowed to sell or buy extra credits ($100 worth of credits at a time), effectively increasing or decreasing their monetary budget and carbon budget, and thereby changing their expenditure patterns. This was done iteratively until each household could no longer improve its utility, and no household that started below its carbon budget was allowed to exceed the same. The MATLAB code used for this simulation is presented in Appendix F.

Constrained maximization of the multimodal translog utility specification in MATLAB is time consuming and can give suboptimal results. To avoid this problem, 10 distinct and random starting values were used for each households' expenditures (X_i values), and the set resulting in maximum utility was used.

Besides numerical and computational issues, other caveats should be noted before presenting results. First, this methodology involves significant aggregation of distinctive expenditures within most categories. This assumption implies that each dollar spent within a category will have the same impact (in terms of GHG emissions and a household's marginal utility). This preference specification can be quite limiting for certain emissions-saving (and other) behaviors that exist. Categories like Gasoline are quite homogeneous, but categories like Air Travel and Public Transport offer many options with different price, emissions, and comfort levels. Even the Other Expenditures category includes a tremendous diversity of energy implications. Ideally, substitution among alternatives within a category (e.g., a well insulated home versus a poorly insulated home, beef-based versus vegetarian meals, a full airplane versus one at 50 percent occupancy) should be enabled to allow households to achieve lower carbon emissions by shifting to less energy- or less-carbon-intensive purchases. Therefore, average emissions predicted here will be somewhat higher than expected, in some ways representing a "worst-case scenario" – but still more flexible than other work to date (by Metcalf [1999], Wier et al. [2005], Grainger and Kolstad [2009]) which assumes simple I-O models to estimate impacts at a disaggregate level (rather than a more flexible demand structure, as achieved with the translog function used here, allowing for disaggregate analysis). The next chapter summarizes the emissions and welfare impact results of the four scenarios modeled, across the 445 CEX households.

CHAPTER 9: RESULTS OF CARBON POLICY SCENARIOS

Expenditure shares by good type were predicted under the base scenario (no-change) and under the two tax and four cap-and-trade policy scenarios. Since these simulations have a long run-time, this analysis was performed on 10 percent sample of the CEX data set, or 445 households. Figure 9.1 plots the translog's expected maximized (or indirect) utility versus household expenditure from the base-case results. As expected (and desired by theory, at the level of individual households [rather than this plot across the 10-percent sample]), maximized utility is increasing and concave with expenditures (Deaton and Muellauer 1980). The spread around the mean utility value corresponding to each expenditure value results mainly from the different prices for vehicle use faced by each household, depending on the type of vehicles they hold.

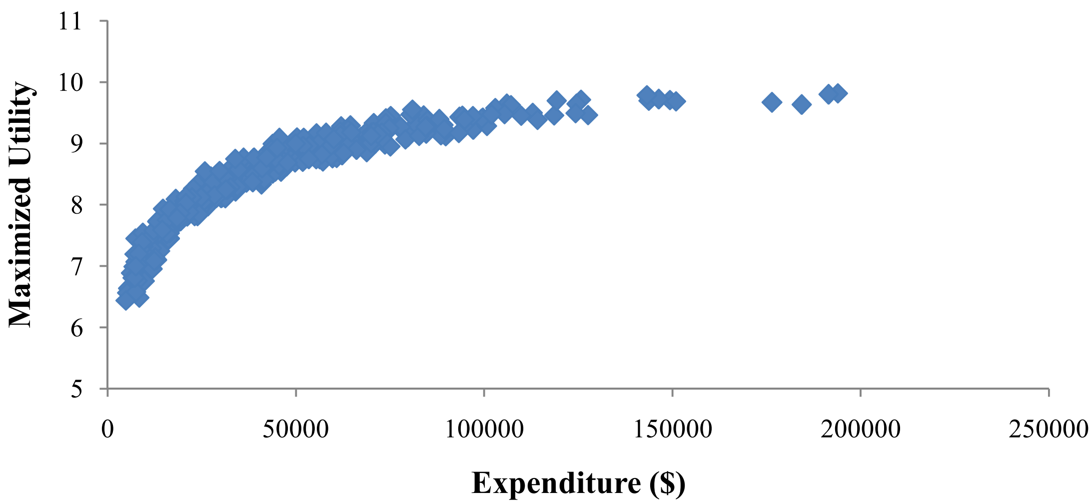


Figure 9.1: Household Utility (Maximized) vs. Annual Expenditures in the Base Case

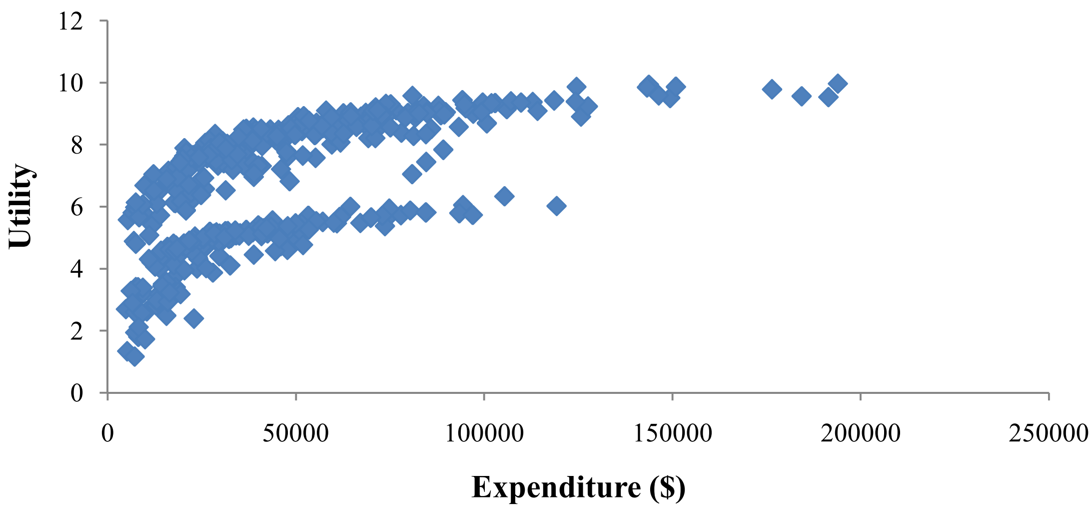


Figure 9.2: Household Utility vs. Annual Expenditures

Figure 9.2 plots the translog utility (at base year expenses) versus the total household expenditure. As expected, most utility values at actual expenditures exhibit higher dispersion across households than the maximized utilities. The following sections present the CO2e emissions and household welfare estimates under different policy scenarios. The final section presents the results of the different revenue redistribution strategies under carbon tax setting.

9.1 Average Emissions

The expenditures by goods category predicted under each scenario were used to estimate the CO_2e emissions for each household in the 10% sample from the CEX 2002 dataset, using Table 8.4's emission estimates. Households were then grouped across six income categories, and average CO_2e emissions per household in each of the income categories were computed (for each of the four policy scenarios) and compared to the base case (business as usual) results, as shown in Table 9.1.

Table 9.1: Average CO2e Emissions (Tons per Year) Across Household Types

	Overall	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Income Class		<$20k	$20-30k	$30-45k	$45-60k	$60-100k	>$100k
#Households	445	88	84	97	60	92	24
Avg. Income	$42,543	$13,168	$24,833	$36,711	$52,219	$75,191	$132,380
Base CO_2 Emissions	22.9	8.3	15.5	21.5	25.6	35.1	76.8
-Tax $50/ton	15.7	6.1	10.4	14.2	18.2	24.3	51.2
-Tax $100/ton	12.1	4.8	8.7	10.0	12.8	18.5	43.3
-Cap 10 tons ($50)	17.7	8.0	14.2	18.3	23.3	26.1	31.7
-Cap 10 tons ($100)	17.5	8.1	13.8	17.8	21.8	26.9	30.5
-Cap 15 tons ($50)	20.9	8.8	14.7	20.1	26.8	34.4	41.2
-Cap 15 tons ($100)	20.7	9.2	15.3	20.7	26.7	32.5	39.5

Note: Cap-and-trade: X($Y) means caps of X tons/person/year on CO2e, with excess credits traded at $Y/ton

A tax of $100/ton leads to an average decrease of 47.2% (highest across all tax and cap-and-trade scenarios) in overall CO_2e emissions, while a tax of $50/ton leads to a 31.4% decrease. A reduction – of 23.6% – is observed when households are capped at 10 tons of CO2e per person per year and excess credits can be sold at a rate of $100/ton. Average emissions are predicted to fall for all households, under both carbon tax scenarios (except for low income household under 15 ton cap). Deep emissions cuts (up to almost 60%) are observed for high income households under both cap-and-trade scenarios, due to high (estimated) starting emissions levels for those with such high expenditures. Emissions of lower-income households are found to increase slightly, on average, as compared to the base, thanks to added income via sale of excess carbon credits. Figures 9.3 to 9.6 compare emissions estimates against household expenditure across the four different scenarios. Emissions follow a roughly linear trend, on average, versus expenditures, with the policy scenarios offering lower slopes than the base case.

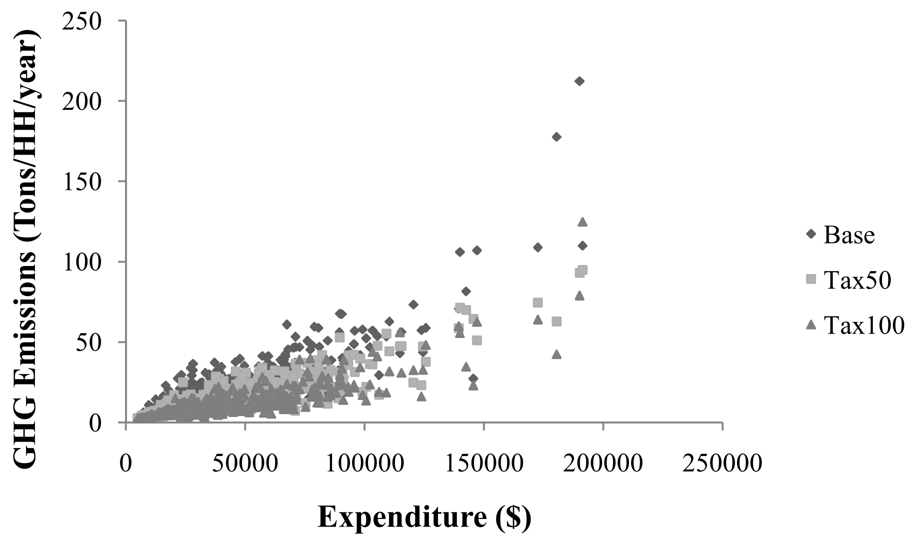


Figure 9.3: Emissions Comparisons – Base vs. Tax (50 and 100)

When compared to the base case and tax-policy cases, cap-and-trade scenarios exhibit a much higher dispersion in emissions estimates across households. The significant scatter or vertical spread around average emissions levels, at each level of household expenditure, arises from variable vehicle ownership and use profiles, as well as variable prices across other categories and also because the households' emissions are capped as a function of household size, with single-person households capped at 10 or 15 tons, and larger households enjoy much higher caps.

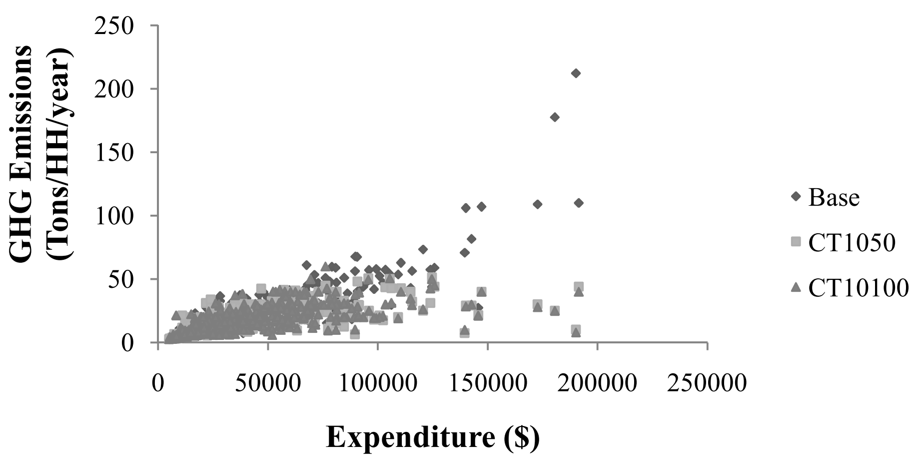


Figure 9.4: Emissions Comparisons – Base vs. Cap (10)-and-Trade.

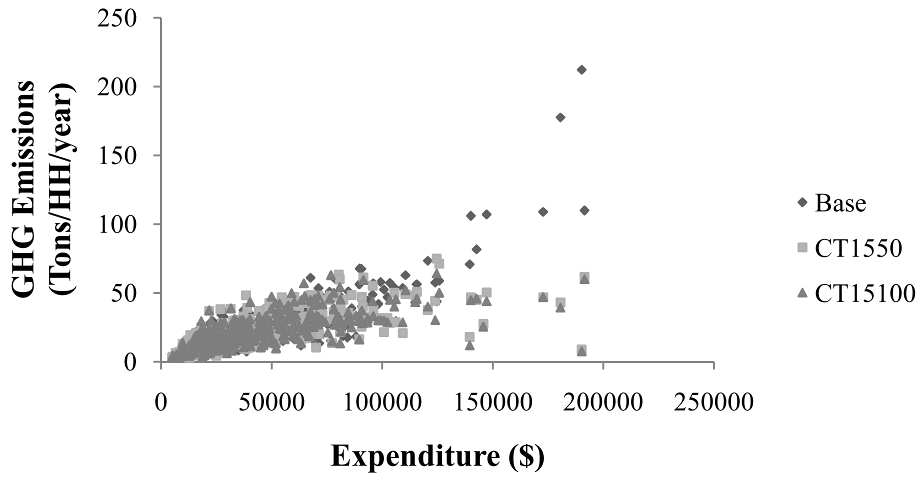


Figure 9.5: Emissions Comparisons – Base vs. Cap (15)-and-Trade

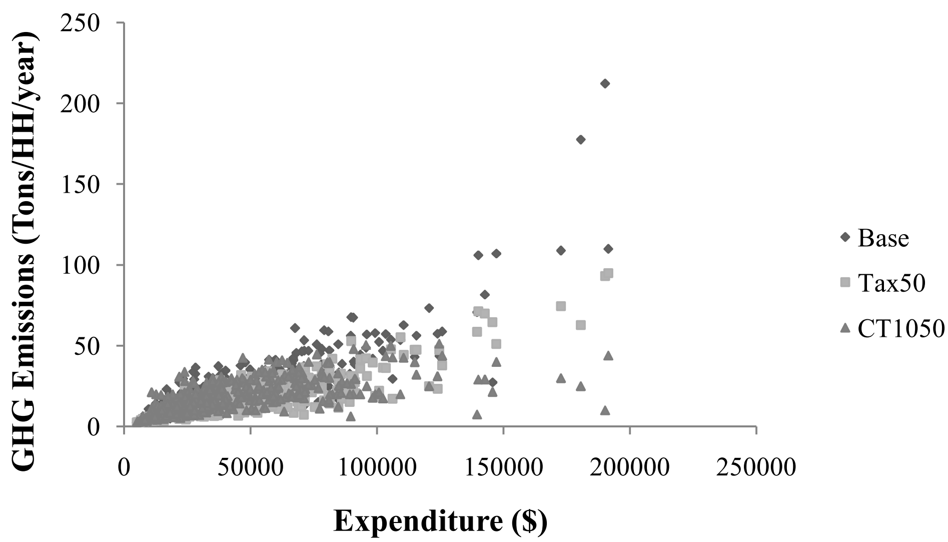


Figure 9.6: Emissions Comparisons – Base vs. Tax (50) vs. Cap (10)-and-Trade

Under the two tax policies, CO_2e emissions reductions (as a percentage of base emissions) appear rather uniformly distributed across different income categories, while much deeper percentage cuts emerge for higher income households under the two cap-and-trade scenarios. Low-income households respond the most to the $100-per-ton tax case, but they are expected to increase CO2e emissions under the cap-and-trade policy (when compared to their behaviors under the two tax scenarios), thanks to additional income from credit sales. Higher-income households respond the most under the 10-ton cap (per household member, per year), since more than 70% high-income households emit more than 10 tons per member. Emission reduction under both the policies are much less than desired by policy makers. With more flexibility in consumption and production innovations, more reductions are expected than these "worst-case scenario" results. Of course, another key question is the welfare implications of these policies, a topic discussed in the next section.

9.2 Welfare Estimates

Table 9.2 presents the annual welfare implications of policies across household classes, using equivalent variation and presented as a percentage of household income.

Table 9.2: Annual Welfare Implications of Policies Across Household Classes (Percent of Income)

	Overall	**Class1**	**Class2**	**Class3**	**Class4**	**Class5**	**Class6**
Income Class		<20k	$20-30k	$30-45k	$45-60k	$60-100k	>$100k
Tax $50/ton	-5,662	-3,359	-5,864	-7,674	-5,621	-5,902	-8,480
Tax $100/ton	-7,496	-3,889	-6,918	-8,508	-8,072	-9,902	-13,851
Cap 10 tons ($50)	-9,226	-3,119	-6,420	-9,365	-12,717	-15,774	-16,120
Cap 10 tons ($100)	-8,616	-2,752	-6,488	-8,215	-8,714	-13,488	-29,928
Cap 15 tons ($50)	-9,477	-3,014	-6,489	-10,260	-13,565	-14,378	-20,774
Cap 15 tons ($100)	-8,998	-2,422	-6,842	-8,685	-10,665	-16,399	-19,793
Equivalent Variation as % of Income							
Tax $50/ton	-18.2%	-26.1%	-23.7%	-20.9%	-10.7%	-8.0%	-6.3%
Tax $100/ton	-22.3%	-30.3	-27.9	-23.2	-15.3	-13.4	-10.9
Cap 10 tons ($50)	-23.2%	-23.1	-25.8	-25.4	-24.2	-20.7	-12.2
Cap 10 tons ($100)	-20.7%	-20.2	-25.7	-22.1	-16.5	-18.4	-21.3
Cap 15 tons ($50)	-23.6%	-21.8	-25.9	-27.9	-25.9	-19.4	-15.6
Cap 15 tons ($100)	-21.6%	-16.8	-27.3	-23.5	-20.5	-22.7	-17.6

As expected, both types of policies are predicted to result in a welfare loss across all household types. The impacts are significant in all policy cases, and for most classes (averaging about 20 percent of income or annual expenditures). As mentioned earlier, however, this model of just 9 goods categories is highly restrictive, and actual responses to such policies will be moderated by the provision of close substitutes that significantly lower CO2e emissions (e.g., more efficient refrigerator or better insulated home). In the absence of ample substitution opportunities, these represent the worst-case results.

While higher-income households experience a higher loss under the more stringent of the two cap-and-trade policies, low-income households are least impacted under the 15-ton cap with a trading price of $100 per ton, thanks to the extra income such credit sales bring them. Another important observation is that carbon taxes appear more regressive than the cap-and-trade policies (with the highest income households experiencing only minimal welfare impact under the two tax policies). However, such taxes bear much revenue which may be redistributed in some way to households, thus addressing some of these implications.

9.3 Tax Revenue Re-distribution Schemes

Under the cap-and-trade policy, the government does enjoy tax revenues. Redistributing the revenues collected from either tax policy can make such policies revenue neutral and less regressive, while garnering more support for such policies (Metcalf 1999; Shammin and Bullard 2009). There are many ways in which such tax revenues can be redistributed, and Table 9.3 presents the average CO2e tax payments made by different household types (as absolute values and as percentages of household income).

Table 9.3: Average CO2e Tax Payments by Different Household Types

	Overall	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Tax $50/ton	$2,618	$1,090	$1,745	$2,368	$3,140	$4,126	$7,565
% of Income	6.75%	8.25%	7.05%	6.45%	6.02%	5.52%	5.71%
Tax $100/ton	$3,673	$1,512	$2,452	$3,129	$4,206	$5,923	$11,486
% of Income	9.36%	11.52%	9.91%	8.53%	8.07%	7.85%	8.63%

As shown in Table 9.3, tax payments vary widely across household categories, but not as a share of income (e.g., $2413 vs. $8609 and 6.5% vs. 4.6% in the $50/ton case). Given the uniformity in effects as a share of income, it is interesting how variable welfare impacts are across income categories for the tax policies (-16% to -1.1% for the $50 tax, in Table 9.2). Table 9.3's tax payments as a share of income may not suggest regressivity, but Table 9.2's results do. Fortunately, here are ways to address such regressivity, by redistributing carbon-tax revenues. Here, two different schemes have been evaluated: uniform redistribution and distribution in proportion to household income, as presented in Tables 9.4 and 9.5.

Table 9.4: Average Gains and Losses under Uniform Redistribution of Carbon Tax Revenues

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Tax $50/ton	$1,516	$862	$239	-$533	-$1,519	-$4,959
% of Income	14.54%	3.56%	0.73%	-0.99%	-1.99%	-3.66%
Tax $100/ton	$2,144	$1,204	$527	-$550	-$2,267	-$7,829
% of Income	20.44%	4.97%	1.54%	-1.01%	-2.89%	-5.75%

Table 9.5: Average Gains and Losses under Redistribution Proportional to Household Incomes

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Tax $50/ton	-$280	-$216	-$109	$74	$502	$582
% of Income	-2.09%	-0.89%	-0.30%	0.14%	0.63%	0.44%
Tax $100/ton	-$375	-$308	$40	$302	$568	-$58
% of Income	-2.89%	-1.27%	0.10%	0.57%	0.79%	0.01%

As suggested by Table 9.4, the uniform redistribution scheme predicts a net gain for low-income households, and a net loss for high-income households. In contrast, the proportional redistribution strategy resulted in a net loss for low-income households and a net gain for high-income households, though much less in absolute values. These comparisons show how the details of tax redistribution can be critical, in terms of stakeholder impact. Of course, additional income (in the form of income tax rebates, for example) would cause such households to spend more, thereby lessening CO_2e reductions. Nonetheless, such tax benefits can garner fundamental support for such policies.

CHAPTER 10: CONCLUSIONS

Here, a translog model was applied to CEX data with substitution across 9 goods categories and within the the vehicle use category. Under pure taxation, emission cuts are distributed uniformly across different income classes, while under cap-and-trade emission cuts are predicted to come mainly from higher-income households. A $100/ton tax was predicted to generate 38% reduction in GHG emissions (assuming just 9 goods categories and no substitution within these, except for vehicle expenses). Welfare implications suggest that a carbon tax is regressive, while higher-income households are most affected under cap-and-trade scenarios (thanks to imposition of caps in proportion to household size). Low-income households may raise their CO2e emissions under a cap-and-trade policy, thanks to increased incomes via sale of excess credit.

The results presented here do not determine which climate policy is best for the U.S. public. While carbon-tax policies may offer minimal pain for households if coupled with revenue redistribution in proportion to household incomes, their emissions reductions are less certain. Regardless of the exact tax or cap, this work provides a useful framework for evaluating such policies in detail, and offers multiple directions for future work.

One significant limitation of this work (and of other studies in this topic area) is the lack of substitution within consumer goods categories. With more flexible and detailed consumption opportunities, actual welfare impacts should be less severe, and GHG savings greater than predicted here. while this work's separate category for vehicle choice, use and expenses help reflect a key opportunity for substitution (across 19 vehicle types), more flexible behavioral models – allowing for additional substitution opportunities need – are likely to better capture the behavioral shifts resulting from such carbon policies.

In addition, the cost of acquiring carbon credits trading is assumed exogenous in this analysis, which may not be the case in reality. Simulation of a credit trading market may be useful to include, so that the market clears. Also, the category of Other Expenditures currently does not have any emissions associated with it, but should. This item, along with emission assumptions for other categories – like food consumption, needs to be refined for more accurate estimation. As noted earlier, studying the resulting effects from simultaneous introduction of climate policies (e.g., vehicle feebates and carbon taxes) will be helpful in anticipating the regressivity and benefits accurately. Nonetheless, this work provides the important framework for studying household's response to policy changes and presents techniques for estimating impacts in terms of emission reduction and welfare.

APPENDIX A: VEHICLE CHOICE SURVEY QUESTIONNAIRE

US 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 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.
- You are not obligated to participate in the survey and you can stop at anytime.
- 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
Professor of Transportation Engineering & Faculty Sponsor

Section 1 - Travel

1. Which of the following is your **primary means of travel** for the following activities? (Please select one means of travel for each activity.)

	Walk	Bicycle	Drive Alone	Drive with others (Carpool)	Bus	Not applicable
Work	□	□	□	□	□	□
School	□	□	□	□	□	□
Food Shopping	□	□	□	□	□	□
Non-food Shopping	□	□	□	□	□	□
Errand/Personal Business	□	□	□	□	□	□
Social Activity	□	□	□	□	□	□

2. How many **trips** did you make for the following purposes in the **last seven (7) days** (for example, number of visits to a destination would be counted as number of trips to that destination)?

	0	1-2	3-4	5-6	7-8	9 or more
Work	□	□	□	□	□	□
School	□	□	□	□	□	□
Food Shopping	□	□	□	□	□	□
Non-food Shopping	□	□	□	□	□	□
Errand/Personal Business	□	□	□	□	□	□
Social Activity	□	□	□	□	□	□

3. When traveling from **home**, How **far** are the following locations **ONE-WAY**? (Please specify the distance in **miles** for each of the most frequently visited locations.)

	Work place	Grocery store	Bus or Rail stop	Airport	Downtown
How **FAR** are each of the following locations from your home?					

4. Please answer the following questions about **LONG DISTANCE TRAVEL** (where your destination was **more than 100 miles** away from your starting location) over the **PAST TWELVE (12) MONTHS** (Please enter the number of round trips).

	Plane	Train (e.g. Amtrak) or Bus (e.g. Greyhound)	Auto
How many **ROUND TRIPS** did you make using this form of transport?			
How many **MILES (TOTAL)** did you travel using this form of transport for **LONG** distance travel?			

6. Please specify the number of **transit (Rail or Bus) stops** within **0.25 mile** (1/4 mile) of your home?

( ) Zero (0)
( ) One (1)
( ) Two (2)
( ) Three (3)
( ) Four or more (4+) (please specify)

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

____
____

Section 2- Current and Past Vehicles

8. 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							

9. 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 _____

10. 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.)

____

11. 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

12. 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

13. 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	_____	_____

14. 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.	□	□

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

____

16. 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.

If "yes" in question 16 go to 17, else go to 20.

17. 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					

18. 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	☐	☐	☐	☐	☐

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

____

20. 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 am/we are thinking to **BUY** a vehicle and **SELL** 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.

If decision is to "sell" (option2) or "buy and sell" (option3) go to question 21 else question 22

21. 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	______	______	______

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

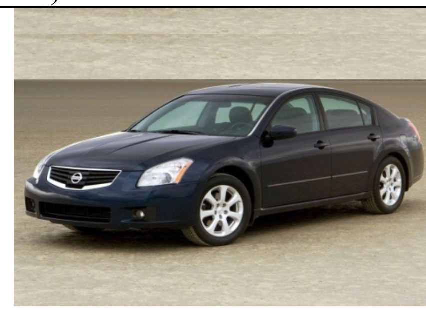
( ) I would definitely buy a **NEW** vehicle.
( ) I would probably buy a **NEW** vehicle.
( ) I **dont know** whether the purchased vehicle would be NEW or USED.
( ) I would **probably** buy a **USED** vehicle.
( ) I would **definitely** buy a **USED** vehicle.

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

____
____
____
____
____

Section 3 - Consumer Vehicle Choice Preference

24. 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* ☐

25. 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* ☐

26. 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* ☐

27. 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* ☐

28. If you had to **BUY** or LEASE a new vehicle in the coming month, and could choose one of the following two vehicles, which would you **BUY** or LEASE? (**Note**: 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.)

	
Electric Range per Charge: 30 miles **Gasoline Range per Gallon: 45 miles** **Purchase Price: $33,000** **Charging Time: 2 hours** ***Plug-In Hybrid Prius***	**Electric Range per Charge: 100 miles** **No gas tank available** **Purchase Price: $42,500** **Charging Time: 4 to 8 hours** ***Nissan Leaf Plug-In Electric Vehicle***

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

____
____
____
____
____

Section 4 - Vehicle Policy

30. 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.

31. 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

If "yes" in question 31 go to question 32, else go to question 33.

32. How **far** from your parking spot is there a garage or a carport with **access** to **electricity** which can be used to charge a plug-in hybrid vehicle (**PHEV**)?

( ) Less than 25 feet
( ) 25-50 feet
( ) 50-75 feet
( ) 75-100 feet
( ) More than 100 feet

33. How many **parking spots** does your residential unit have?

( ) Zero (0)
( ) One (1)
( ) Two (2)
( ) Three (3)
( ) Four (4)
( ) Five (5)
( ) More than five (5) (Please specify a number.) _______________

34. At your **workplace**, how far is a carport or garage with **access** to **electricity**?

( ) Less than 25 feet
( ) 25-50 feet
( ) 50-75 feet
( ) 75-100 feet
( ) More than 100 feet
( ) Not aware of the distance

35. 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
If "adapt to the change" in question 35 go to question 36, else go to question 37.

36. 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

37. 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

38. 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.

39. 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	_____

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

____
____

Section 4 - Demographics

41. 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.)

42. How many persons **UNDER the age of 16 years** usually live in your home?
- ( ) Zero (0)
- ( ) One (1)
- ( ) Two (2)
- ( ) Three (3)
- ( ) Four or more (4+) (Please specify exact number.)

43. 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.)

44. How many persons in your household hold a **DRIVER'S LICENSE**?
- ( ) Zero (0)
- ( ) One (1)
- ( ) Two (2)
- ( ) Three (3)
- ( ) Four or more (4+) (Please specify exact number.)

45. Which of the following best describes your households **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

46. What is your **AGE**?
- ( ) Less than 25 years old
- ( ) 25-34
- ( ) 35-44
- ( ) 45-54
- ( ) 55-64
- ( ) 65 or more years of age

47. Are you male or female?

( ) Male
( ) Female

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

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

49. 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.

50. 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

51. What **state** do you live in?

____

52. What **city** do you live in?

____

53. 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.

____

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

APPENDIX B: VEHICLE PRICE AND FUEL ECONOMY ASSUMPTIONS

Table B1: Price and Fuel Economy Assumptions

Vehicle Type	Price Assumption (miles per gallon)	Fuel Economy Assumption (Dollars)	Notes
Subcompact	20.65	$29,600	
Compact	26.6	$16,700	
Midsize	19	$25,600	
Large	17.57	$30,700	
Luxury	18.61	$48,100	
Smart Car	36	$17,000	
HEV	46	$25,000	
PHEV	45	$33,000	PHEV 30
CUV	18.08	$26,900	
SUV	15.1	$35,200	
SUV_HEV	22	$47,000	
SUV_PHEV	22	$57,000	AER 30 miles, 15kWh battery
Pickup	14.67	$26,800	
Pickup_HEV	21	$36,000	
Pickup_PHEV	21	$46,000	AER 30 miles, 15kWh battery
Van	15.18	$27,400	
Van_HEV	23	$38,000	
Van_PHEV	23	$48,000	AER 30 miles, 15kWh battery
Hummer	16	$61,500	

APPENDIX C: MATLAB CODE FOR PART I'S VEHICLE FLEET EVOLUTION

This MATLAB code is only for the year one of the simulation for TREND scenario. The model's demographic evolution code comes from Tirumalachetty (2009) and is not included here.

```
clear all;
year=1
hnew=csvread('C:\RA_Binny\Vehicle ownership\demographic new\hh_1.csv');
%hold=csvread('baseyear_synthetic_evolved.csv');
hold=xlsread('baseyear_synthetic.xls');
[a,b]=size(hnew);
[e,f]=size(hold);
veh=zeros(a,42);

gasprice=2.6;
counter=0;

for i=1:a


            %carrying forward all the evolved household char's through
            %microsimulation models
            veh(i,1)=hnew(i,1);

            veh(i,2)=hnew(i,3);
            veh(i,3)=hnew(i,60);
            veh(i,4)=hnew(i,20)+hnew(i,21);
            veh(i,5)=hnew(i,4);
            veh(i,6)=hnew(i,61);
            veh(i,20)=hnew(i,1);
            veh(i,21)=hnew(i,2);

            veh(i,23)=hnew(i,22);
            veh(i,24)=hnew(i,23);

            veh(i,38)=hnew(i,15)+hnew(i,16)+hnew(i,17);
            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)<30000
              veh(i,22)=1;
            else
             veh(i,22)=0;
            end

            if hnew(i,4)>=75000
              veh(i,42)=1;
            else
             veh(i,42)=0;
            end


     for j=i:e

         %copying vehicle details if an existing household
        if hnew(i,1)==hold(j,1)
            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,26:37)=hold(j,26:37);
           % veh(i,40)=hold(j,40);
            last=i;
            break;
        end
    end
end


 for i=last:a

        %vehicle details for new households
            veh(i,7)=hnew(i,6);         % no of vehicles
            veh(i,8:12)=hnew(i,48:52);   % vehicle type

            %assinging price and MPG to vehicles
            if veh(i,7)>0
            for v=1:veh(i,7)

                if hnew(i,47+v)==1
                    veh(i,25+2*v-1)=18.08;
                    veh(i,26+2*v-1)=0.269;
                elseif hnew(i,47+v)==2
                    veh(i,25+2*v-1)=17.57;
                    veh(i,26+2*v-1)=0.307;
                elseif hnew(i,47+v)==3
                    veh(i,25+2*v-1)=18.61;
                    veh(i,26+2*v-1)=0.48;
                elseif hnew(i,47+v)==4
                    veh(i,25+2*v-1)=19;
                    veh(i,26+2*v-1)=0.256;
                elseif hnew(i,47+v)==5
                    veh(i,25+2*v-1)=14.67;
                    veh(i,26+2*v-1)=0.268;
                elseif hnew(i,47+v)==6
```

```
            veh(i,25+2*v-1)=20.65;
            veh(i,26+2*v-1)=0.296;
        elseif hnew(i,47+v)==7
            veh(i,25+2*v-1)=26.6;
            veh(i,26+2*v-1)=0.167;
        elseif hnew(i,47+v)==8
            veh(i,25+2*v-1)=15.1;
            veh(i,26+2*v-1)=0.352;
        elseif hnew(i,47+v)==9
            veh(i,25+2*v-1)=15.18;
            veh(i,26+2*v-1)=0.274;
        end

    end
    end

    % age of vehicles allotment for new households
  if veh(i,7)>0
    for v=1:veh(i,7)
        x(v)=rand;
        if x(v)<0.015625
            veh(i,14+v-1)=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(-1-0.5748*hh(i,7)+0.3019*hh(i,4)-
0.0335*hh(i,3)+0.0551*max(hh(i,14:19))-0.5231*hh(i,22));%acquire
         temp(i,2)=exp(-
3.50+0.0000781*hh(i,23)+0.0551*max(hh(i,14:19)));%dispose
         temp(i,3)=exp(-2.10+0.4153*hh(i,38)-0.7601*hh(i,6));
%replace
```

```
        temp(i,4)=1;%do nothing
        temp(i,5)=sum(temp(i,1:4));
        temp(i,6)=temp(i,1)/temp(i,5);
        temp(i,7)=(temp(i,1)+temp(i,2))/temp(i,5);
        temp(i,8)=(temp(i,1)+temp(i,2)+temp(i,3))/temp(i,5);
        temp(i,9)=1;

     end


 for i=1:c


    x=rand;

    if x<temp(i,6)%vehicle bought
        counter=counter+1;
        utilt(i,1)= exp(-0.4195-5.206*gasprice/20.65-
4.004*0.296+0.6849*hh(i,39)+0.2331*hh(i,7)+1.03/100000*hh(i,5)+1.23/10000*
hh(i,24));    %COMPACT
        utilt(i,2)= exp(-0.5770-5.206*gasprice/26.6-
4.004*0.167+0.01122*hh(i,3));
%SUBCOMPACT
        utilt(i,3)= exp(-0.8044-5.206*gasprice/17.57-
4.004*0.307+0.4621*hh(i,6)+0.2331*hh(i,7));
%Large
        utilt(i,4)= exp(0.4305-5.206*gasprice/18.61-
4.004*0.48+0.4621*hh(i,6)+0.2331*hh(i,7)+0.3962*hh(i,42)+7.2/100000*hh(i,2
4));      %luxury
        utilt(i,5)= exp(-2.735-5.206*gasprice/36-4.004*0.17-
0.5978*hh(i,2));
% smart car
        utilt(i,6)= exp(-1.519-5.206*gasprice/46-
4.004*0.25+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
% HEV
        utilt(i,7)= exp(-0.0917-5.206*gasprice/45-4.004*0.33-
1.097*hh(i,4)+1.404/10000*hh(i,23));
%PHEV
        utilt(i,8)= exp(0.8855-5.206*gasprice/18.08-
4.004*0.269+0.2331*hh(i,7));
%CUV
        utilt(i,9)= exp(-0.4299-5.206*gasprice/15.1-
4.004*0.352+0.3287*hh(i,6)+0.01122*hh(i,3)+0.2331*hh(i,7)+4.15/1000000*hh(
i,5));     %SUV
        utilt(i,10)= exp(-2.819-5.206*gasprice/22-
4.004*0.47+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
          %SUV_HEV
        utilt(i,11)= exp(-1.391-5.206*gasprice/22-4.004*0.57-
1.097*hh(i,4)+1.404/10000*hh(i,23));
     %SUV_PHEV
        utilt(i,12)= exp(-0.2429-5.206*gasprice/14.67-
4.004*0.268+1.208*hh(i,6)+0.3651*hh(i,4)+6.02/1000000*hh(i,5)/hh(i,2));
%PICKUP
```

```
         utilt(i,13)= exp(-2.632-5.206*gasprice/21-
4.004*0.36+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
            %PICKUP_HEV
         utilt(i,14)= exp(-1.204-5.206*gasprice/21-4.004*0.46-
1.097*hh(i,4)+1.404/10000*hh(i,23));
%PICKUP_PHEV
         utilt(i,15)= exp(-5.206*gasprice/15.18-4.004*0.274);
%Van
         utilt(i,16)= exp(-2.389-5.206*gasprice/23-
4.004*0.38+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
            %Van_HEV
         utilt(i,17)= exp(-0.9612-5.206*gasprice/23-4.004*0.48-
1.097*hh(i,4)+1.404/10000*hh(i,23));
      %Van_PHEV
         utilt(i,18)= exp(-2.721-5.206*gasprice/16-
4.004*0.615+1.208*hh(i,6)+2.24*hh(i,39));
%Hummer
         utilt(i,19)= exp(0.8695-5.206*gasprice/19-4.004*0.256);
                                                   %Midsize
         utilt(i,20)=sum(utilt(i,1:19));

                  % calculating the cummulative probabilites
         utilt(i,21)= utilt(i,1)/utilt(i,20);
         utilt(i,22)= sum(utilt(i,1:2))/utilt(i,20);
         utilt(i,23)= sum(utilt(i,1:3))/utilt(i,20);
         utilt(i,24)= sum(utilt(i,1:4))/utilt(i,20);
         utilt(i,25)= sum(utilt(i,1:5))/utilt(i,20);
         utilt(i,26)= sum(utilt(i,1:6))/utilt(i,20);
         utilt(i,27)= sum(utilt(i,1:7))/utilt(i,20);
         utilt(i,28)= sum(utilt(i,1:8))/utilt(i,20);
         utilt(i,29)= sum(utilt(i,1:9))/utilt(i,20);
         utilt(i,30)= sum(utilt(i,1:10))/utilt(i,20);
         utilt(i,31)= sum(utilt(i,1:11))/utilt(i,20);
         utilt(i,32)= sum(utilt(i,1:12))/utilt(i,20);
         utilt(i,33)= sum(utilt(i,1:13))/utilt(i,20);
         utilt(i,34)= sum(utilt(i,1:14))/utilt(i,20);
         utilt(i,35)= sum(utilt(i,1:15))/utilt(i,20);
         utilt(i,36)= sum(utilt(i,1:16))/utilt(i,20);
         utilt(i,37)= sum(utilt(i,1:17))/utilt(i,20);
         utilt(i,38)= sum(utilt(i,1:18))/utilt(i,20);
         utilt(i,39)= sum(utilt(i,1:19))/utilt(i,20);

         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,21)
                       hh(i,25)=1;
                       hh(i,13)=6;
```

```
                    hh(i,36)=20.65;
                    hh(i,37)=0.296;
                    elseif y>utilt(i,21) && y< utilt(i,22)
                    hh(i,25)=2;
                    hh(i,13)=7;
                    hh(i,36)=26.6;
                    hh(i,37)=0.167;
                    elseif y>utilt(i,22) && y< utilt(i,23)
                    hh(i,25)=3;
                    hh(i,13)=2;
                    hh(i,36)=17.57;
                    hh(i,37)=0.307;
                    elseif y>utilt(i,23) && y< utilt(i,24)
                    hh(i,25)=4;
                    hh(i,13)=3;
                    hh(i,36)=18.61;
                    hh(i,37)=0.481;
                    elseif y>utilt(i,24) && y< utilt(i,25)
                    hh(i,25)=5;
                    hh(i,13)=7;
                    hh(i,36)=36;
                    hh(i,37)=0.17;
                    elseif y>utilt(i,25) && y< utilt(i,26)
                    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,26) && y< utilt(i,27)
                    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,27) && y< utilt(i,28)
                    hh(i,25)=8;
                    hh(i,13)=1;
                    hh(i,36)=18.08;
                    hh(i,37)=0.269;
                    elseif y>utilt(i,28) && y< utilt(i,29)
                    hh(i,25)=9;
                    hh(i,13)=8;
                    hh(i,36)=15.1;
                    hh(i,37)=0.352;
                    elseif y>utilt(i,29) && y< utilt(i,30)
                    hh(i,25)=10;
                    hh(i,13)=8;
                    hh(i,36)=22;
                    hh(i,37)=0.47;
                    elseif y>utilt(i,30) && y< utilt(i,31)
                    hh(i,25)=11;
                    hh(i,13)=8;
                    hh(i,36)=22;
                    hh(i,37)=0.57;
```

```
                elseif y>utilt(i,31) && y< utilt(i,32)
                hh(i,25)=12;
                hh(i,13)=5;
                hh(i,36)=14.67;
                hh(i,37)=0.268;
                elseif y>utilt(i,32) && y< utilt(i,33)
                hh(i,25)=13;
                hh(i,13)=5;
                hh(i,36)=21;
                hh(i,37)=0.36;
                elseif y>utilt(i,33) && y< utilt(i,34)
                hh(i,25)=14;
                hh(i,13)=5;
                hh(i,36)=21;
                hh(i,37)=0.46;
                elseif y>utilt(i,34) && y< utilt(i,35)
                hh(i,25)=15;
                hh(i,13)=9;
                hh(i,36)=15.18;
                hh(i,37)=0.274;
                elseif y>utilt(i,35) && y< utilt(i,36)
                hh(i,25)=16;
                hh(i,13)=9;
                hh(i,36)=23;
                hh(i,37)=0.38;
                elseif y>utilt(i,36) && y< utilt(i,37)
                hh(i,25)=17;
                hh(i,13)=9;
                hh(i,36)=23;
                hh(i,37)=0.48;
                elseif y>utilt(i,37) && y< utilt(i,38)
                hh(i,25)=18;
                hh(i,13)=1;
                hh(i,36)=16;
                hh(i,37)=0.615;
                elseif y>utilt(i,38) && y< utilt(i,39)
                hh(i,25)=19;
                hh(i,13)=4;
                hh(i,36)=19;
                hh(i,37)=0.256;
              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,21)
                hh(i,25)=1;
                hh(i,12)=6;
                hh(i,34)=20.65;
                hh(i,35)=0.296;
                elseif y>utilt(i,21) && y< utilt(i,22)
                hh(i,25)=2;
                hh(i,12)=7;
```

```
                        hh(i,34)=26.6;
                        hh(i,35)=0.167;
                        elseif y>utilt(i,22) && y< utilt(i,23)
                        hh(i,25)=3;
                        hh(i,12)=2;
                        hh(i,34)=17.57;
                        hh(i,35)=0.307;
                        elseif y>utilt(i,23) && y< utilt(i,24)
                        hh(i,25)=4;
                        hh(i,12)=3;
                        hh(i,34)=18.61;
                        hh(i,35)=0.481;
                        elseif y>utilt(i,24) && y< utilt(i,25)
                        hh(i,25)=5;
                        hh(i,12)=7;
                        hh(i,34)=36;
                        hh(i,35)=0.17;
                        elseif y>utilt(i,25) && y< utilt(i,26)
                        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,26) && y< utilt(i,27)
                        hh(i,25)=7;
                        hh(i,12)=4;%substituing midsize vehicle class for a
PHEV purchase
                        hh(i,34)=45;
                        hh(i,35)=0.33;
                        elseif y>utilt(i,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,12)=1;
                        hh(i,34)=18.08;
                        hh(i,35)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,12)=8;
                        hh(i,34)=15.1;
                        hh(i,35)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,12)=8;
                        hh(i,34)=22;
                        hh(i,35)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,12)=8;
                        hh(i,34)=22;
                        hh(i,35)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,12)=5;
                        hh(i,34)=14.67;
                        hh(i,35)=0.268;
```

```
          elseif y>utilt(i,32) && y< utilt(i,33)
          hh(i,25)=13;
          hh(i,12)=5;
          hh(i,34)=21;
          hh(i,35)=0.36;
          elseif y>utilt(i,33) && y< utilt(i,34)
          hh(i,25)=14;
          hh(i,12)=5;
          hh(i,34)=21;
          hh(i,35)=0.46;
          elseif y>utilt(i,34) && y< utilt(i,35)
          hh(i,25)=15;
          hh(i,12)=9;
          hh(i,34)=15.18;
          hh(i,35)=0.274;
          elseif y>utilt(i,35) && y< utilt(i,36)
          hh(i,25)=16;
          hh(i,12)=9;
          hh(i,34)=23;
          hh(i,35)=0.38;
          elseif y>utilt(i,36) && y< utilt(i,37)
          hh(i,25)=17;
          hh(i,12)=9;
          hh(i,34)=23;
          hh(i,35)=0.48;
          elseif y>utilt(i,37) && y< utilt(i,38)
          hh(i,25)=18;
          hh(i,12)=1;
          hh(i,34)=16;
          hh(i,35)=0.615;
          elseif y>utilt(i,38) && y< utilt(i,39)
          hh(i,25)=19;
          hh(i,12)=4;
          hh(i,34)=19;
          hh(i,35)=0.256;
        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,21)
          hh(i,25)=1;
          hh(i,11)=6;
          hh(i,32)=20.65;
          hh(i,33)=0.296;
          elseif y>utilt(i,21) && y< utilt(i,22)
          hh(i,25)=2;
          hh(i,11)=7;
          hh(i,32)=26.6;
          hh(i,33)=0.167;
          elseif y>utilt(i,22) && y< utilt(i,23)
          hh(i,25)=3;
```

```
                        hh(i,11)=2;
                        hh(i,32)=17.57;
                        hh(i,33)=0.307;
                        elseif y>utilt(i,23) && y< utilt(i,24)
                        hh(i,25)=4;
                        hh(i,11)=3;
                        hh(i,32)=18.61;
                        hh(i,33)=0.481;
                        elseif y>utilt(i,24) && y< utilt(i,25)
                        hh(i,25)=5;
                        hh(i,11)=7;
                        hh(i,32)=36;
                        hh(i,33)=0.17;
                        elseif y>utilt(i,25) && y< utilt(i,26)
                        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,26) && y< utilt(i,27)
                        hh(i,25)=7;
                        hh(i,11)=4;%substituing midsize vehicle class for a
PHEV purchase
                        hh(i,32)=45;
                        hh(i,33)=0.33;
                        elseif y>utilt(i,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,11)=1;
                        hh(i,32)=18.08;
                        hh(i,33)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,11)=8;
                        hh(i,32)=15.1;
                        hh(i,33)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,11)=8;
                        hh(i,32)=22;
                        hh(i,33)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,11)=8;
                        hh(i,32)=22;
                        hh(i,33)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,11)=5;
                        hh(i,32)=14.67;
                        hh(i,33)=0.268;
                        elseif y>utilt(i,32) && y< utilt(i,33)
                        hh(i,25)=13;
                        hh(i,11)=5;
                        hh(i,32)=21;
```

```
          hh(i,33)=0.36;
          elseif y>utilt(i,33) && y< utilt(i,34)
          hh(i,25)=14;
          hh(i,11)=5;
          hh(i,32)=21;
          hh(i,33)=0.46;
          elseif y>utilt(i,34) && y< utilt(i,35)
          hh(i,25)=15;
          hh(i,11)=9;
          hh(i,32)=15.18;
          hh(i,33)=0.274;
          elseif y>utilt(i,35) && y< utilt(i,36)
          hh(i,25)=16;
          hh(i,11)=9;
          hh(i,32)=23;
          hh(i,33)=0.38;
          elseif y>utilt(i,36) && y< utilt(i,37)
          hh(i,25)=17;
          hh(i,11)=9;
          hh(i,32)=23;
          hh(i,33)=0.48;
          elseif y>utilt(i,37) && y< utilt(i,38)
          hh(i,25)=18;
          hh(i,11)=1;
          hh(i,32)=16;
          hh(i,33)=0.615;
          elseif y>utilt(i,38) && y< utilt(i,39)
          hh(i,25)=19;
          hh(i,11)=4;
          hh(i,32)=19;
          hh(i,33)=0.256;
        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,21)
          hh(i,25)=1;
          hh(i,10)=6;
          hh(i,30)=20.65;
          hh(i,31)=0.296;
          elseif y>utilt(i,21) && y< utilt(i,22)
          hh(i,25)=2;
          hh(i,10)=7;
          hh(i,30)=26.6;
          hh(i,31)=0.167;
          elseif y>utilt(i,22) && y< utilt(i,23)
          hh(i,25)=3;
          hh(i,10)=2;
```

```
                        hh(i,30)=17.57;
                        hh(i,31)=0.307;
                        elseif y>utilt(i,23) && y< utilt(i,24)
                        hh(i,25)=4;
                        hh(i,10)=3;
                        hh(i,30)=18.61;
                        hh(i,31)=0.481;
                        elseif y>utilt(i,24) && y< utilt(i,25)
                        hh(i,25)=5;
                        hh(i,10)=7;
                        hh(i,30)=36;
                        hh(i,31)=0.17;
                        elseif y>utilt(i,25) && y< utilt(i,26)
                        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,26) && y< utilt(i,27)
                        hh(i,25)=7;
                        hh(i,10)=4;%substituing midsize vehicle class for a
PHEV purchase
                        hh(i,30)=45;
                        hh(i,31)=0.33;
                        elseif y>utilt(i,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,10)=1;
                        hh(i,30)=18.08;
                        hh(i,31)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,10)=8;
                        hh(i,30)=15.1;
                        hh(i,31)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,10)=8;
                        hh(i,30)=22;
                        hh(i,31)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,10)=8;
                        hh(i,30)=22;
                        hh(i,31)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,10)=5;
                        hh(i,30)=14.67;
                        hh(i,31)=0.268;
                        elseif y>utilt(i,32) && y< utilt(i,33)
                        hh(i,25)=13;
                        hh(i,10)=5;
                        hh(i,30)=21;
                        hh(i,31)=0.36;
```

```
                  elseif y>utilt(i,33) && y< utilt(i,34)
                  hh(i,25)=14;
                  hh(i,10)=5;
                  hh(i,30)=21;
                  hh(i,31)=0.46;
                  elseif y>utilt(i,34) && y< utilt(i,35)
                  hh(i,25)=15;
                  hh(i,10)=9;
                  hh(i,30)=15.18;
                  hh(i,31)=0.274;
                  elseif y>utilt(i,35) && y< utilt(i,36)
                  hh(i,25)=16;
                  hh(i,10)=9;
                  hh(i,30)=23;
                  hh(i,31)=0.38;
                  elseif y>utilt(i,36) && y< utilt(i,37)
                  hh(i,25)=17;
                  hh(i,10)=9;
                  hh(i,30)=23;
                  hh(i,31)=0.48;
                  elseif y>utilt(i,37) && y< utilt(i,38)
                  hh(i,25)=18;
                  hh(i,10)=1;
                  hh(i,30)=16;
                  hh(i,31)=0.615;
                  elseif y>utilt(i,38) && y< utilt(i,39)
                  hh(i,25)=19;
                  hh(i,10)=4;
                  hh(i,30)=19;
                  hh(i,31)=0.256;
                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,21)
                  hh(i,25)=1;
                  hh(i,9)=6;
                  hh(i,28)=20.65;
                  hh(i,29)=0.296;
                  elseif y>utilt(i,21) && y< utilt(i,22)
                  hh(i,25)=2;
                  hh(i,9)=7;
                  hh(i,28)=26.6;
                  hh(i,29)=0.167;
                  elseif y>utilt(i,22) && y< utilt(i,23)
                  hh(i,25)=3;
                  hh(i,9)=2;
                  hh(i,28)=17.57;
                  hh(i,29)=0.307;
                  elseif y>utilt(i,23) && y< utilt(i,24)
```

```
                        hh(i,25)=4;
                        hh(i,9)=3;
                        hh(i,28)=18.61;
                        hh(i,29)=0.481;
                        elseif y>utilt(i,24) && y< utilt(i,25)
                        hh(i,25)=5;
                        hh(i,9)=7;
                        hh(i,28)=36;
                        hh(i,29)=0.17;
                        elseif y>utilt(i,25) && y< utilt(i,26)
                        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,26) && y< utilt(i,27)
                        hh(i,25)=7;
                        hh(i,9)=4;%substituing midsize vehicle class for a
PHEV purchase
                        hh(i,28)=45;
                        hh(i,29)=0.33;
                        elseif y>utilt(i,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,9)=1;
                        hh(i,28)=18.08;
                        hh(i,29)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,9)=8;
                        hh(i,28)=15.1;
                        hh(i,29)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,9)=8;
                        hh(i,28)=22;
                        hh(i,29)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,9)=8;
                        hh(i,28)=22;
                        hh(i,29)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,9)=5;
                        hh(i,28)=14.67;
                        hh(i,29)=0.268;
                        elseif y>utilt(i,32) && y< utilt(i,33)
                        hh(i,25)=13;
                        hh(i,9)=5;
                        hh(i,28)=21;
                        hh(i,29)=0.36;
                        elseif y>utilt(i,33) && y< utilt(i,34)
                        hh(i,25)=14;
                        hh(i,9)=5;
```

```
                  hh(i,28)=21;
                  hh(i,29)=0.46;
                  elseif y>utilt(i,34) && y< utilt(i,35)
                  hh(i,25)=15;
                  hh(i,9)=9;
                  hh(i,28)=15.18;
                  hh(i,29)=0.274;
                  elseif y>utilt(i,35) && y< utilt(i,36)
                  hh(i,25)=16;
                  hh(i,9)=9;
                  hh(i,28)=23;
                  hh(i,29)=0.38;
                  elseif y>utilt(i,36) && y< utilt(i,37)
                  hh(i,25)=17;
                  hh(i,9)=9;
                  hh(i,28)=23;
                  hh(i,29)=0.48;
                  elseif y>utilt(i,37) && y< utilt(i,38)
                  hh(i,25)=18;
                  hh(i,9)=1;
                  hh(i,28)=16;
                  hh(i,29)=0.615;
                  elseif y>utilt(i,38) && y< utilt(i,39)
                  hh(i,25)=19;
                  hh(i,9)=4;
                  hh(i,28)=19;
                  hh(i,29)=0.256;
                end



elseif hh(i,7)==0 % zero vehicle households
            hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
            hh(i,14)=hh(i,14)+1;

              if y<utilt(i,21)
                hh(i,25)=1;
                hh(i,8)=6;
                hh(i,26)=20.65;
                hh(i,27)=0.296;
                elseif y>utilt(i,21) && y< utilt(i,22)
                hh(i,25)=2;
                hh(i,8)=7;
                hh(i,26)=26.6;
                hh(i,27)=0.167;
                elseif y>utilt(i,22) && y< utilt(i,23)
                hh(i,25)=3;
                hh(i,8)=2;
                hh(i,26)=17.57;
                hh(i,27)=0.307;
                elseif y>utilt(i,23) && y< utilt(i,24)
                hh(i,25)=4;
                hh(i,8)=3;
```

```
                        hh(i,26)=18.61;
                        hh(i,27)=0.481;
                        elseif y>utilt(i,24) && y< utilt(i,25)
                        hh(i,25)=5;
                        hh(i,8)=7;
                        hh(i,26)=36;
                        hh(i,27)=0.17;
                        elseif y>utilt(i,25) && y< utilt(i,26)
                        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;
                        elseif y>utilt(i,26) && y< utilt(i,27)
                        hh(i,25)=7;
                        hh(i,8)=4;%substituing midsize vehicle class for a
PHEV purchase
                        hh(i,26)=45;
                        hh(i,27)=0.33;
                        elseif y>utilt(i,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,8)=1;
                        hh(i,26)=18.08;
                        hh(i,27)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,8)=8;
                        hh(i,26)=15.1;
                        hh(i,27)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,8)=8;
                        hh(i,26)=22;
                        hh(i,27)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,8)=8;
                        hh(i,26)=22;
                        hh(i,27)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,8)=5;
                        hh(i,26)=14.67;
                        hh(i,27)=0.268;
                        elseif y>utilt(i,32) && y< utilt(i,33)
                        hh(i,25)=13;
                        hh(i,8)=5;
                        hh(i,26)=21;
                        hh(i,27)=0.36;
                        elseif y>utilt(i,33) && y< utilt(i,34)
                        hh(i,25)=14;
                        hh(i,8)=5;
                        hh(i,26)=21;
                        hh(i,27)=0.46;
```

```
                      elseif y>utilt(i,34) && y< utilt(i,35)
                      hh(i,25)=15;
                      hh(i,8)=9;
                      hh(i,26)=15.18;
                      hh(i,27)=0.274;
                      elseif y>utilt(i,35) && y< utilt(i,36)
                      hh(i,25)=16;
                      hh(i,8)=9;
                      hh(i,26)=23;
                      hh(i,27)=0.38;
                      elseif y>utilt(i,36) && y< utilt(i,37)
                      hh(i,25)=17;
                      hh(i,8)=9;
                      hh(i,26)=23;
                      hh(i,27)=0.48;
                      elseif y>utilt(i,37) && y< utilt(i,38)
                      hh(i,25)=18;
                      hh(i,8)=1;
                      hh(i,26)=16;
                      hh(i,27)=0.615;
                      elseif y>utilt(i,38) && y< utilt(i,39)
                      hh(i,25)=19;
                      hh(i,8)=4;
                      hh(i,26)=19;
                      hh(i,27)=0.256;
                    end

        end

      %% vehicle disposed

       elseif x>temp(i,6) && x<temp(i,7)%vehicle disposed

           counter=counter+1;

               for iter =1:hh(i,7)
                 if hh(i,7+iter)==1 % cuv
                       utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.0000885*hh(i,24)+0.6311*hh(i,6)+0.0186*hh(i,3)-
0.3848*hh(i,4)-1.6895;
```

```
                  elseif hh(i,7+iter)==2 % large
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.7813;

                  elseif hh(i,7+iter)==3 % luxury
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1);

                  elseif hh(i,7+iter)==4 % midsize
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.000106*hh(i,23)+0.9601*hh(i,39);

                  elseif hh(i,7+iter)==5 % truck
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.000106*hh(i,23)+0.9601*hh(i,39);

                  elseif hh(i,7+iter)==6 % compact
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.1112*hh(i,7)+0.0000417*hh(i,5)-
0.3848*hh(i,4)+0.000106*hh(i,23)+0.9601*hh(i,39);

                  elseif hh(i,7+iter)==7 % subcompact
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-1.3331-0.0000885*hh(i,24);

                  elseif hh(i,7+iter)==8 % suv
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-
1)+0.000106*hh(i,23)+0.00000417*hh(i,5)+0.9601*hh(i,39);

                  elseif hh(i,7+iter)==9 % van
                      utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.0000885*hh(i,24)-
0.000241*hh(i,23)+0.9601*hh(i,39);
               end


              end



          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
%

                  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


                  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,2)<utility(i,1) &&
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,1) &&
utility(i,3)<utility(i,2)
                          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

%
                       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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3)
                           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,1) &&
utility(i,3)<utility(i,2)  && 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,2)<utility(i,1) &&
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

%

                        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,1) &&
utility(i,5)<utility(i,2)  && utility(i,5)<utility(i,3) &&
utility(i,5)<utility(i,4)
                            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,1) &&
utility(i,3)<utility(i,2)  && 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,2)<utility(i,1) &&
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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3) &&
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

%
```

```
                        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,1) &&
utility(i,6)<utility(i,2)  && utility(i,6)<utility(i,3) &&
utility(i,6)<utility(i,4) && utility(i,6)<utility(i,5)
                           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,1) &&
utility(i,3)<utility(i,2) && 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,2)<utility(i,1) &&
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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3) &&
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,1) &&
utility(i,5)<utility(i,2)  && utility(i,5)<utility(i,3) &&
utility(i,5)<utility(i,4) && 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
    %%%%%%%%%%%%%%%%%%%REPLACE%%%%%%%%%%%%%%%%%%%%
     elseif x>temp(i,7) && x<temp(i,8)

         counter=counter+1;

         %%%%%%%%%%%%%%%%%%%%%%%%%BUY%%%%%%%%%%%%%%%%%%%%

         utilt(i,1)= exp(-0.4195-5.206*gasprice/20.65-
4.004*0.296+0.6849*hh(i,39)+0.2331*hh(i,7)+1.03/100000*hh(i,5)+1.23/10000*
hh(i,24));    %COMPACT
         utilt(i,2)= exp(-0.5770-5.206*gasprice/26.6-
4.004*0.167+0.01122*hh(i,3));
%SUBCOMPACT
         utilt(i,3)= exp(-0.8044-5.206*gasprice/17.57-
4.004*0.307+0.4621*hh(i,6)+0.2331*hh(i,7));
%Large
```

```
        utilt(i,4)= exp(0.4305-5.206*gasprice/18.61-
4.004*0.48+0.4621*hh(i,6)+0.2331*hh(i,7)+0.3962*hh(i,42)+7.2/100000*hh(i,2
4));      %luxury
        utilt(i,5)= exp(-2.735-5.206*gasprice/36-4.004*0.17-
0.5978*hh(i,2));
% smart car
        utilt(i,6)= exp(-1.519-5.206*gasprice/46-
4.004*0.25+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
% HEV
        utilt(i,7)= exp(-0.0917-5.206*gasprice/45-4.004*0.33-
1.097*hh(i,4)+1.404/10000*hh(i,23));
%PHEV
        utilt(i,8)= exp(0.8855-5.206*gasprice/18.08-
4.004*0.269+0.2331*hh(i,7));
%CUV
        utilt(i,9)= exp(-0.4299-5.206*gasprice/15.1-
4.004*0.352+0.3287*hh(i,6)+0.01122*hh(i,3)+0.2331*hh(i,7)+4.15/1000000*hh(
i,5));     %SUV
        utilt(i,10)= exp(-2.819-5.206*gasprice/22-
4.004*0.47+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
                                                           %SUV_HEV
        utilt(i,11)= exp(-1.391-5.206*gasprice/22-4.004*0.57-
1.097*hh(i,4)+1.404/10000*hh(i,23));
                       %SUV_PHEV
        utilt(i,12)= exp(-0.2429-5.206*gasprice/14.67-
4.004*0.268+1.208*hh(i,6)+0.3651*hh(i,4)+6.02/1000000*hh(i,5)/hh(i,2));
%PICKUP
        utilt(i,13)= exp(-2.632-5.206*gasprice/21-
4.004*0.36+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
                                                           %PICKUP_HEV
        utilt(i,14)= exp(-1.204-5.206*gasprice/21-4.004*0.46-
1.097*hh(i,4)+1.404/10000*hh(i,23));
                             %PICKUP_PHEV
        utilt(i,15)= exp(-5.206*gasprice/15.18-4.004*0.274);
%Van
        utilt(i,16)= exp(-2.389-5.206*gasprice/23-
4.004*0.38+0.01122*hh(i,3)+0.2331*hh(i,7)+1.404/10000*hh(i,23));
                                                     %Van_HEV
        utilt(i,17)= exp(-0.9612-5.206*gasprice/23-4.004*0.48-
1.097*hh(i,4)+1.404/10000*hh(i,23));
                       %Van_PHEV
        utilt(i,18)= exp(-2.721-5.206*gasprice/16-
4.004*0.615+1.208*hh(i,6)+2.24*hh(i,39));
%Hummer
        utilt(i,19)= exp(0.8695-5.206*gasprice/19-4.004*0.256);
                                                           %Midsize
        utilt(i,20)=sum(utilt(i,1:19));

                  % calculating the cummulative probabilites
        utilt(i,21)= utilt(i,1)/utilt(i,20);
        utilt(i,22)= sum(utilt(i,1:2))/utilt(i,20);
        utilt(i,23)= sum(utilt(i,1:3))/utilt(i,20);
        utilt(i,24)= sum(utilt(i,1:4))/utilt(i,20);
        utilt(i,25)= sum(utilt(i,1:5))/utilt(i,20);
```

```
        utilt(i,26)= sum(utilt(i,1:6))/utilt(i,20);
        utilt(i,27)= sum(utilt(i,1:7))/utilt(i,20);
        utilt(i,28)= sum(utilt(i,1:8))/utilt(i,20);
        utilt(i,29)= sum(utilt(i,1:9))/utilt(i,20);
        utilt(i,30)= sum(utilt(i,1:10))/utilt(i,20);
        utilt(i,31)= sum(utilt(i,1:11))/utilt(i,20);
        utilt(i,32)= sum(utilt(i,1:12))/utilt(i,20);
        utilt(i,33)= sum(utilt(i,1:13))/utilt(i,20);
        utilt(i,34)= sum(utilt(i,1:14))/utilt(i,20);
        utilt(i,35)= sum(utilt(i,1:15))/utilt(i,20);
        utilt(i,36)= sum(utilt(i,1:16))/utilt(i,20);
        utilt(i,37)= sum(utilt(i,1:17))/utilt(i,20);
        utilt(i,38)= sum(utilt(i,1:18))/utilt(i,20);
        utilt(i,39)= sum(utilt(i,1:19))/utilt(i,20);

        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,21)
                       hh(i,25)=1;
                       hh(i,13)=6;
                       hh(i,36)=20.65;
                       hh(i,37)=0.296;
                       elseif y>utilt(i,21) && y< utilt(i,22)
                       hh(i,25)=2;
                       hh(i,13)=7;
                       hh(i,36)=26.6;
                       hh(i,37)=0.167;
                       elseif y>utilt(i,22) && y< utilt(i,23)
                       hh(i,25)=3;
                       hh(i,13)=2;
                       hh(i,36)=17.57;
                       hh(i,37)=0.307;
                       elseif y>utilt(i,23) && y< utilt(i,24)
                       hh(i,25)=4;
                       hh(i,13)=3;
                       hh(i,36)=18.61;
                       hh(i,37)=0.481;
                       elseif y>utilt(i,24) && y< utilt(i,25)
                       hh(i,25)=5;
                       hh(i,13)=7;
                       hh(i,36)=36;
                       hh(i,37)=0.17;
                       elseif y>utilt(i,25) && y< utilt(i,26)
                       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,26) && y< utilt(i,27)
                        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,27) && y< utilt(i,28)
                        hh(i,25)=8;
                        hh(i,13)=1;
                        hh(i,36)=18.08;
                        hh(i,37)=0.269;
                        elseif y>utilt(i,28) && y< utilt(i,29)
                        hh(i,25)=9;
                        hh(i,13)=8;
                        hh(i,36)=15.1;
                        hh(i,37)=0.352;
                        elseif y>utilt(i,29) && y< utilt(i,30)
                        hh(i,25)=10;
                        hh(i,13)=8;
                        hh(i,36)=22;
                        hh(i,37)=0.47;
                        elseif y>utilt(i,30) && y< utilt(i,31)
                        hh(i,25)=11;
                        hh(i,13)=8;
                        hh(i,36)=22;
                        hh(i,37)=0.57;
                        elseif y>utilt(i,31) && y< utilt(i,32)
                        hh(i,25)=12;
                        hh(i,13)=5;
                        hh(i,36)=14.67;
                        hh(i,37)=0.268;
                        elseif y>utilt(i,32) && y< utilt(i,33)
                        hh(i,25)=13;
                        hh(i,13)=5;
                        hh(i,36)=21;
                        hh(i,37)=0.36;
                        elseif y>utilt(i,33) && y< utilt(i,34)
                        hh(i,25)=14;
                        hh(i,13)=5;
                        hh(i,36)=21;
                        hh(i,37)=0.46;
                        elseif y>utilt(i,34) && y< utilt(i,35)
                        hh(i,25)=15;
                        hh(i,13)=9;
                        hh(i,36)=15.18;
                        hh(i,37)=0.274;
                        elseif y>utilt(i,35) && y< utilt(i,36)
                        hh(i,25)=16;
                        hh(i,13)=9;
                        hh(i,36)=23;
                        hh(i,37)=0.38;
                        elseif y>utilt(i,36) && y< utilt(i,37)
                        hh(i,25)=17;
```

```
                    hh(i,13)=9;
                    hh(i,36)=23;
                    hh(i,37)=0.48;
                    elseif y>utilt(i,37) && y< utilt(i,38)
                    hh(i,25)=18;
                    hh(i,13)=1;
                    hh(i,36)=16;
                    hh(i,37)=0.615;
                    elseif y>utilt(i,38) && y< utilt(i,39)
                    hh(i,25)=19;
                    hh(i,13)=4;
                    hh(i,36)=19;
                    hh(i,37)=0.256;
                  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,21)
                    hh(i,25)=1;
                    hh(i,12)=6;
                    hh(i,34)=20.65;
                    hh(i,35)=0.296;
                    elseif y>utilt(i,21) && y< utilt(i,22)
                    hh(i,25)=2;
                    hh(i,12)=7;
                    hh(i,34)=26.6;
                    hh(i,35)=0.167;
                    elseif y>utilt(i,22) && y< utilt(i,23)
                    hh(i,25)=3;
                    hh(i,12)=2;
                    hh(i,34)=17.57;
                    hh(i,35)=0.307;
                    elseif y>utilt(i,23) && y< utilt(i,24)
                    hh(i,25)=4;
                    hh(i,12)=3;
                    hh(i,34)=18.61;
                    hh(i,35)=0.481;
                    elseif y>utilt(i,24) && y< utilt(i,25)
                    hh(i,25)=5;
                    hh(i,12)=7;
                    hh(i,34)=36;
                    hh(i,35)=0.17;
                    elseif y>utilt(i,25) && y< utilt(i,26)
                    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,26) && y< utilt(i,27)
                    hh(i,25)=7;
                    hh(i,12)=4;%substituing midsize vehicle class for a
PHEV purchase
```

```
hh(i,34)=45;
hh(i,35)=0.33;
elseif y>utilt(i,27) && y< utilt(i,28)
hh(i,25)=8;
hh(i,12)=1;
hh(i,34)=18.08;
hh(i,35)=0.269;
elseif y>utilt(i,28) && y< utilt(i,29)
hh(i,25)=9;
hh(i,12)=8;
hh(i,34)=15.1;
hh(i,35)=0.352;
elseif y>utilt(i,29) && y< utilt(i,30)
hh(i,25)=10;
hh(i,12)=8;
hh(i,34)=22;
hh(i,35)=0.47;
elseif y>utilt(i,30) && y< utilt(i,31)
hh(i,25)=11;
hh(i,12)=8;
hh(i,34)=22;
hh(i,35)=0.57;
elseif y>utilt(i,31) && y< utilt(i,32)
hh(i,25)=12;
hh(i,12)=5;
hh(i,34)=14.67;
hh(i,35)=0.268;
elseif y>utilt(i,32) && y< utilt(i,33)
hh(i,25)=13;
hh(i,12)=5;
hh(i,34)=21;
hh(i,35)=0.36;
elseif y>utilt(i,33) && y< utilt(i,34)
hh(i,25)=14;
hh(i,12)=5;
hh(i,34)=21;
hh(i,35)=0.46;
elseif y>utilt(i,34) && y< utilt(i,35)
hh(i,25)=15;
hh(i,12)=9;
hh(i,34)=15.18;
hh(i,35)=0.274;
elseif y>utilt(i,35) && y< utilt(i,36)
hh(i,25)=16;
hh(i,12)=9;
hh(i,34)=23;
hh(i,35)=0.38;
elseif y>utilt(i,36) && y< utilt(i,37)
hh(i,25)=17;
hh(i,12)=9;
hh(i,34)=23;
hh(i,35)=0.48;
elseif y>utilt(i,37) && y< utilt(i,38)
hh(i,25)=18;
```

```
                    hh(i,12)=1;
                    hh(i,34)=16;
                    hh(i,35)=0.615;
                    elseif y>utilt(i,38) && y< utilt(i,39)
                    hh(i,25)=19;
                    hh(i,12)=4;
                    hh(i,34)=19;
                    hh(i,35)=0.256;
                  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,21)
                    hh(i,25)=1;
                    hh(i,11)=6;
                    hh(i,32)=20.65;
                    hh(i,33)=0.296;
                    elseif y>utilt(i,21) && y< utilt(i,22)
                    hh(i,25)=2;
                    hh(i,11)=7;
                    hh(i,32)=26.6;
                    hh(i,33)=0.167;
                    elseif y>utilt(i,22) && y< utilt(i,23)
                    hh(i,25)=3;
                    hh(i,11)=2;
                    hh(i,32)=17.57;
                    hh(i,33)=0.307;
                    elseif y>utilt(i,23) && y< utilt(i,24)
                    hh(i,25)=4;
                    hh(i,11)=3;
                    hh(i,32)=18.61;
                    hh(i,33)=0.481;
                    elseif y>utilt(i,24) && y< utilt(i,25)
                    hh(i,25)=5;
                    hh(i,11)=7;
                    hh(i,32)=36;
                    hh(i,33)=0.17;
                    elseif y>utilt(i,25) && y< utilt(i,26)
                    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,26) && y< utilt(i,27)
                    hh(i,25)=7;
                    hh(i,11)=4;%substituing midsize vehicle class for a
PHEV purchase
                    hh(i,32)=45;
                    hh(i,33)=0.33;
                    elseif y>utilt(i,27) && y< utilt(i,28)
                    hh(i,25)=8;
```

```
hh(i,11)=1;
hh(i,32)=18.08;
hh(i,33)=0.269;
elseif y>utilt(i,28) && y< utilt(i,29)
hh(i,25)=9;
hh(i,11)=8;
hh(i,32)=15.1;
hh(i,33)=0.352;
elseif y>utilt(i,29) && y< utilt(i,30)
hh(i,25)=10;
hh(i,11)=8;
hh(i,32)=22;
hh(i,33)=0.47;
elseif y>utilt(i,30) && y< utilt(i,31)
hh(i,25)=11;
hh(i,11)=8;
hh(i,32)=22;
hh(i,33)=0.57;
elseif y>utilt(i,31) && y< utilt(i,32)
hh(i,25)=12;
hh(i,11)=5;
hh(i,32)=14.67;
hh(i,33)=0.268;
elseif y>utilt(i,32) && y< utilt(i,33)
hh(i,25)=13;
hh(i,11)=5;
hh(i,32)=21;
hh(i,33)=0.36;
elseif y>utilt(i,33) && y< utilt(i,34)
hh(i,25)=14;
hh(i,11)=5;
hh(i,32)=21;
hh(i,33)=0.46;
elseif y>utilt(i,34) && y< utilt(i,35)
hh(i,25)=15;
hh(i,11)=9;
hh(i,32)=15.18;
hh(i,33)=0.274;
elseif y>utilt(i,35) && y< utilt(i,36)
hh(i,25)=16;
hh(i,11)=9;
hh(i,32)=23;
hh(i,33)=0.38;
elseif y>utilt(i,36) && y< utilt(i,37)
hh(i,25)=17;
hh(i,11)=9;
hh(i,32)=23;
hh(i,33)=0.48;
elseif y>utilt(i,37) && y< utilt(i,38)
hh(i,25)=18;
hh(i,11)=1;
hh(i,32)=16;
hh(i,33)=0.615;
elseif y>utilt(i,38) && y< utilt(i,39)
```

```
                      hh(i,25)=19;
                      hh(i,11)=4;
                      hh(i,32)=19;
                      hh(i,33)=0.256;
                    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,21)
                      hh(i,25)=1;
                      hh(i,10)=6;
                      hh(i,30)=20.65;
                      hh(i,31)=0.296;
                      elseif y>utilt(i,21) && y< utilt(i,22)
                      hh(i,25)=2;
                      hh(i,10)=7;
                      hh(i,30)=26.6;
                      hh(i,31)=0.167;
                      elseif y>utilt(i,22) && y< utilt(i,23)
                      hh(i,25)=3;
                      hh(i,10)=2;
                      hh(i,30)=17.57;
                      hh(i,31)=0.307;
                      elseif y>utilt(i,23) && y< utilt(i,24)
                      hh(i,25)=4;
                      hh(i,10)=3;
                      hh(i,30)=18.61;
                      hh(i,31)=0.481;
                      elseif y>utilt(i,24) && y< utilt(i,25)
                      hh(i,25)=5;
                      hh(i,10)=7;
                      hh(i,30)=36;
                      hh(i,31)=0.17;
                      elseif y>utilt(i,25) && y< utilt(i,26)
                      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,26) && y< utilt(i,27)
                      hh(i,25)=7;
                      hh(i,10)=4;%substituing midsize vehicle class for a
PHEV purchase
                      hh(i,30)=45;
                      hh(i,31)=0.33;
                      elseif y>utilt(i,27) && y< utilt(i,28)
                      hh(i,25)=8;
                      hh(i,10)=1;
```

```
hh(i,30)=18.08;
hh(i,31)=0.269;
elseif y>utilt(i,28) && y< utilt(i,29)
hh(i,25)=9;
hh(i,10)=8;
hh(i,30)=15.1;
hh(i,31)=0.352;
elseif y>utilt(i,29) && y< utilt(i,30)
hh(i,25)=10;
hh(i,10)=8;
hh(i,30)=22;
hh(i,31)=0.47;
elseif y>utilt(i,30) && y< utilt(i,31)
hh(i,25)=11;
hh(i,10)=8;
hh(i,30)=22;
hh(i,31)=0.57;
elseif y>utilt(i,31) && y< utilt(i,32)
hh(i,25)=12;
hh(i,10)=5;
hh(i,30)=14.67;
hh(i,31)=0.268;
elseif y>utilt(i,32) && y< utilt(i,33)
hh(i,25)=13;
hh(i,10)=5;
hh(i,30)=21;
hh(i,31)=0.36;
elseif y>utilt(i,33) && y< utilt(i,34)
hh(i,25)=14;
hh(i,10)=5;
hh(i,30)=21;
hh(i,31)=0.46;
elseif y>utilt(i,34) && y< utilt(i,35)
hh(i,25)=15;
hh(i,10)=9;
hh(i,30)=15.18;
hh(i,31)=0.274;
elseif y>utilt(i,35) && y< utilt(i,36)
hh(i,25)=16;
hh(i,10)=9;
hh(i,30)=23;
hh(i,31)=0.38;
elseif y>utilt(i,36) && y< utilt(i,37)
hh(i,25)=17;
hh(i,10)=9;
hh(i,30)=23;
hh(i,31)=0.48;
elseif y>utilt(i,37) && y< utilt(i,38)
hh(i,25)=18;
hh(i,10)=1;
hh(i,30)=16;
hh(i,31)=0.615;
elseif y>utilt(i,38) && y< utilt(i,39)
hh(i,25)=19;
```

```
                    hh(i,10)=4;
                    hh(i,30)=19;
                    hh(i,31)=0.256;
                  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,21)
                    hh(i,25)=1;
                    hh(i,9)=6;
                    hh(i,28)=20.65;
                    hh(i,29)=0.296;
                    elseif y>utilt(i,21) && y< utilt(i,22)
                    hh(i,25)=2;
                    hh(i,9)=7;
                    hh(i,28)=26.6;
                    hh(i,29)=0.167;
                    elseif y>utilt(i,22) && y< utilt(i,23)
                    hh(i,25)=3;
                    hh(i,9)=2;
                    hh(i,28)=17.57;
                    hh(i,29)=0.307;
                    elseif y>utilt(i,23) && y< utilt(i,24)
                    hh(i,25)=4;
                    hh(i,9)=3;
                    hh(i,28)=18.61;
                    hh(i,29)=0.481;
                    elseif y>utilt(i,24) && y< utilt(i,25)
                    hh(i,25)=5;
                    hh(i,9)=7;
                    hh(i,28)=36;
                    hh(i,29)=0.17;
                    elseif y>utilt(i,25) && y< utilt(i,26)
                    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,26) && y< utilt(i,27)
                    hh(i,25)=7;
                    hh(i,9)=4;%substituing midsize vehicle class for a
PHEV purchase
                    hh(i,28)=45;
                    hh(i,29)=0.33;
                    elseif y>utilt(i,27) && y< utilt(i,28)
                    hh(i,25)=8;
                    hh(i,9)=1;
                    hh(i,28)=18.08;
                    hh(i,29)=0.269;
                    elseif y>utilt(i,28) && y< utilt(i,29)
```

```
hh(i,25)=9;
hh(i,9)=8;
hh(i,28)=15.1;
hh(i,29)=0.352;
elseif y>utilt(i,29) && y< utilt(i,30)
hh(i,25)=10;
hh(i,9)=8;
hh(i,28)=22;
hh(i,29)=0.47;
elseif y>utilt(i,30) && y< utilt(i,31)
hh(i,25)=11;
hh(i,9)=8;
hh(i,28)=22;
hh(i,29)=0.57;
elseif y>utilt(i,31) && y< utilt(i,32)
hh(i,25)=12;
hh(i,9)=5;
hh(i,28)=14.67;
hh(i,29)=0.268;
elseif y>utilt(i,32) && y< utilt(i,33)
hh(i,25)=13;
hh(i,9)=5;
hh(i,28)=21;
hh(i,29)=0.36;
elseif y>utilt(i,33) && y< utilt(i,34)
hh(i,25)=14;
hh(i,9)=5;
hh(i,28)=21;
hh(i,29)=0.46;
elseif y>utilt(i,34) && y< utilt(i,35)
hh(i,25)=15;
hh(i,9)=9;
hh(i,28)=15.18;
hh(i,29)=0.274;
elseif y>utilt(i,35) && y< utilt(i,36)
hh(i,25)=16;
hh(i,9)=9;
hh(i,28)=23;
hh(i,29)=0.38;
elseif y>utilt(i,36) && y< utilt(i,37)
hh(i,25)=17;
hh(i,9)=9;
hh(i,28)=23;
hh(i,29)=0.48;
elseif y>utilt(i,37) && y< utilt(i,38)
hh(i,25)=18;
hh(i,9)=1;
hh(i,28)=16;
hh(i,29)=0.615;
elseif y>utilt(i,38) && y< utilt(i,39)
hh(i,25)=19;
hh(i,9)=4;
hh(i,28)=19;
hh(i,29)=0.256;
```

```
                  end



        elseif hh(i,7)==0 % zero vehicle households
                hh(i,7)=hh(i,7)+1;% updating age of vehicle every year
                hh(i,14)=hh(i,14)+1;

                  if y<utilt(i,21)
                    hh(i,25)=1;
                    hh(i,8)=6;
                    hh(i,26)=20.65;
                    hh(i,27)=0.296;
                    elseif y>utilt(i,21) && y< utilt(i,22)
                    hh(i,25)=2;
                    hh(i,8)=7;
                    hh(i,26)=26.6;
                    hh(i,27)=0.167;
                    elseif y>utilt(i,22) && y< utilt(i,23)
                    hh(i,25)=3;
                    hh(i,8)=2;
                    hh(i,26)=17.57;
                    hh(i,27)=0.307;
                    elseif y>utilt(i,23) && y< utilt(i,24)
                    hh(i,25)=4;
                    hh(i,8)=3;
                    hh(i,26)=18.61;
                    hh(i,27)=0.481;
                    elseif y>utilt(i,24) && y< utilt(i,25)
                    hh(i,25)=5;
                    hh(i,8)=7;
                    hh(i,26)=36;
                    hh(i,27)=0.17;
                    elseif y>utilt(i,25) && y< utilt(i,26)
                    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;
                    elseif y>utilt(i,26) && y< utilt(i,27)
                    hh(i,25)=7;
                    hh(i,8)=4;%substituing midsize vehicle class for a
PHEV purchase
                    hh(i,26)=45;
                    hh(i,27)=0.33;
                    elseif y>utilt(i,27) && y< utilt(i,28)
                    hh(i,25)=8;
                    hh(i,8)=1;
                    hh(i,26)=18.08;
                    hh(i,27)=0.269;
                    elseif y>utilt(i,28) && y< utilt(i,29)
                    hh(i,25)=9;
                    hh(i,8)=8;
```

```
  hh(i,26)=15.1;
  hh(i,27)=0.352;
  elseif y>utilt(i,29) && y< utilt(i,30)
  hh(i,25)=10;
  hh(i,8)=8;
  hh(i,26)=22;
  hh(i,27)=0.47;
  elseif y>utilt(i,30) && y< utilt(i,31)
  hh(i,25)=11;
  hh(i,8)=8;
  hh(i,26)=22;
  hh(i,27)=0.57;
  elseif y>utilt(i,31) && y< utilt(i,32)
  hh(i,25)=12;
  hh(i,8)=5;
  hh(i,26)=14.67;
  hh(i,27)=0.268;
  elseif y>utilt(i,32) && y< utilt(i,33)
  hh(i,25)=13;
  hh(i,8)=5;
  hh(i,26)=21;
  hh(i,27)=0.36;
  elseif y>utilt(i,33) && y< utilt(i,34)
  hh(i,25)=14;
  hh(i,8)=5;
  hh(i,26)=21;
  hh(i,27)=0.46;
  elseif y>utilt(i,34) && y< utilt(i,35)
  hh(i,25)=15;
  hh(i,8)=9;
  hh(i,26)=15.18;
  hh(i,27)=0.274;
  elseif y>utilt(i,35) && y< utilt(i,36)
  hh(i,25)=16;
  hh(i,8)=9;
  hh(i,26)=23;
  hh(i,27)=0.38;
  elseif y>utilt(i,36) && y< utilt(i,37)
  hh(i,25)=17;
  hh(i,8)=9;
  hh(i,26)=23;
  hh(i,27)=0.48;
  elseif y>utilt(i,37) && y< utilt(i,38)
  hh(i,25)=18;
  hh(i,8)=1;
  hh(i,26)=16;
  hh(i,27)=0.615;
  elseif y>utilt(i,38) && y< utilt(i,39)
  hh(i,25)=19;
  hh(i,8)=4;
  hh(i,26)=19;
  hh(i,27)=0.256;
end
```

```
      end

        %%%%%%%%%%%%%SELL%%%%%%%%%%%%%%%%%%%%%%%%%
             for iter =1:hh(i,7)
               if hh(i,7+iter)==1 % cuv
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.0000885*hh(i,24)+0.6311*hh(i,6)+0.0186*hh(i,3)-
0.3848*hh(i,4)-1.6895;

                 elseif hh(i,7+iter)==2 % large
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.7813;

                 elseif hh(i,7+iter)==3 % luxury
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1);

                 elseif hh(i,7+iter)==4 % midsize
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.000106*hh(i,23)+0.9601*hh(i,39);

                 elseif hh(i,7+iter)==5 % truck
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.000106*hh(i,23)+0.9601*hh(i,39);

                 elseif hh(i,7+iter)==6 % compact
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)+0.1112*hh(i,7)+0.0000417*hh(i,5)-
0.3848*hh(i,4)+0.000106*hh(i,23)+0.9601*hh(i,39);

                 elseif hh(i,7+iter)==7 % subcompact
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-1.3331-0.0000885*hh(i,24);

                 elseif hh(i,7+iter)==8 % suv
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-
1)+0.000106*hh(i,23)+0.00000417*hh(i,5)+0.9601*hh(i,39);

                 elseif hh(i,7+iter)==9 % van
                     utility(i,iter)=-4.4475*gasprice/hh(i,25+2*iter-1)-
3.3923*hh(i,26+2*iter-1)-0.0000885*hh(i,24)-
0.000241*hh(i,23)+0.9601*hh(i,39);
               end


             end



          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
%

                  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


                  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,2)<utility(i,1) &&
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,1) &&
utility(i,3)<utility(i,2)
                            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

%
                          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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3)
                              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,1) &&
utility(i,3)<utility(i,2)  && 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,2)<utility(i,1) &&
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

%

                        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,1) &&
utility(i,5)<utility(i,2)  && utility(i,5)<utility(i,3) &&
utility(i,5)<utility(i,4)
                            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,1) &&
utility(i,3)<utility(i,2)  && 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,2)<utility(i,1) &&
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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3) &&
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

%

                        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,1) &&
utility(i,6)<utility(i,2)  && utility(i,6)<utility(i,3) &&
utility(i,6)<utility(i,4) && utility(i,6)<utility(i,5)
                           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,1) &&
utility(i,3)<utility(i,2) && 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,2)<utility(i,1) &&
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,1) &&
utility(i,4)<utility(i,2)  && utility(i,4)<utility(i,3) &&
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,1) &&
utility(i,5)<utility(i,2)  && utility(i,5)<utility(i,3) &&
utility(i,5)<utility(i,4) && 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

csvwrite('year1veh_synthetic_evolved.csv',hh);
 counter

  end
```

APPENDIX D: PRICE ASSUMPTIONS BY GOODS CATEGORY

Table A1: Price Assumptions by Goods Category

Region	Category	Mean	Std. Dev.	Units	Notes
Northeast	Electricity	0.114	0.003	$/kWh	Average of all monthly data for 2002
Midwest	Electricity	0.082	0.005		
Southeast	Electricity	0.079	0.003		
West	Electricity	0.111	0.001		
Northeast	Natural Gas	9.496	0.429	$/1000 cuft	Average of all monthly data for 2002
Midwest	Natural Gas	6.796	0.395		
Southeast	Natural Gas	8.299	0.319		
West	Natural Gas	7.852	0.214		
Northeast	Gasoline	1.454	0.117	$/gallon	Average of all monthly data for 2002
Midwest	Gasoline	1.423	0.123		
Southeast	Gasoline	1.371	0.123		
West	Gasoline	1.502	0.131		
Northeast	Food at Home	177.1	0.673	CPI (100 in 1982)	Average of all monthly data for 2002
Midwest	Food at Home	170.1	0.714		
Southeast	Food at Home	171.3	0.512		
West	Food at Home	185.4	0.884		
Northeast	Food away from Home	181.4	1.402	CPI (100 in 1982)	Average of all monthly data for 2002
Midwest	Food away from Home	175.7	1.100		
Southeast	Food away from Home	180.0	1.116		
West	Food away from Home	175.4	1.413		
Northeast	Air Travel	0.160	0.549	$/mile	Average of quarterly data for 2002
Midwest	Air Travel	0.183	0.415		
Southeast	Air Travel	0.184	0.463		
West	Air Travel	0.152	0.327		
Northeast	Public Transport	0.0452	0.1262	$/mile	Computed as (fare/trip)/(miles/trip) for each state and region
Midwest	Public Transport	0.0398	0.1594		
Southeast	Public Transport	0.0211	0.0314		
West	Public Transport	0.0227	0.0424		

Note: Price data for electricity, gas, gasoline and food categories come from www.bls.gov. Airfare data were obtained from http://ostpxweb.dot.gov/, and public transit prices come from http://www.ntdprogram.gov.

APPENDIX E: I-O MODEL RESULTS

Table B1: Price Increases across Sectors, based on I-O Model Results

No	Sector	GHG(tons) from $1M worth of produce	Price Increase (%) under $50/ton tax	Price Increase (%) under $100/ton tax
1	Vegetable and melon farming	1300	6.50	13.00
2	Tree nut farming	1330	6.65	13.30
3	Greenhouse, nursery, and floriculture production	971	4.86	9.71
4	Tobacco farming	3690	18.45	36.90
5	Cotton farming	4290	21.45	42.90
6	Dairy cattle and milk production	4260	21.30	42.60
7	Poultry and egg production	2360	11.80	23.60
8	Logging	632	3.16	6.32
9	Fishing	1310	6.55	13.10
10	Hunting and trapping	708	3.54	7.08
11	Support activities for agriculture and forestry	1450	7.25	14.50
12	Oil and gas extraction	1990	9.95	19.90
13	Coal mining	4240	21.20	42.40
14	Iron ore mining	2860	14.30	28.60
15	Copper, nickel, lead, and zinc mining	1470	7.35	14.70
16	Stone mining and quarrying	1150	5.75	11.50
17	Sand, gravel, clay, and ceramic and refractory	1490	7.45	14.90
18	Other nonmetallic mineral mining and quarrying	1960	9.80	19.60
19	Drilling oil and gas wells	984	4.92	9.84
20	Support activities for oil and gas operations	649	3.25	6.49
21	Electric power generation, transmission, and d	9370	46.85	93.70
22	Natural gas distribution	2430	12.15	24.30
23	Water, sewage and other systems	1780	8.90	17.80
24	Nonresidential commercial and health care structure	589	2.95	5.89
25	Nonresidential manufacturing structures	437	2.19	4.37
26	Other nonresidential structures	612	3.06	6.12
27	Residential permanent site single- and multi-f	659	3.30	6.59
28	Other residential structures	580	2.90	5.80

29	Nonresidential maintenance and repair	624	3.12	6.24
30	Residential maintenance and repair	698	3.49	6.98
31	Dog and cat food manufacturing	1530	7.65	15.30
32	Other animal food manufacturing	2130	10.65	21.30
33	Flour milling and malt manufacturing	2360	11.80	23.60
34	Wet corn milling	4100	20.50	41.00
35	Fats and oils refining and blending	2190	10.95	21.90
36	Breakfast cereal manufacturing	952	4.76	9.52
37	Beet sugar manufacturing	2640	13.20	26.40
38	Chocolate and confectionery manufacturing from	1150	5.75	11.50
39	Confectionery manufacturing from purchased chocolate	932	4.66	9.32
40	Non-chocolate confectionery manufacturing	1030	5.15	10.30
41	Frozen food manufacturing	1390	6.95	13.90
42	Fruit and vegetable canning, pickling, and dry	1010	5.05	10.10
43	Cheese manufacturing	2530	12.65	25.30
44	Dry, condensed, and evaporated dairy product m	2130	10.65	21.30
45	Ice cream and frozen dessert manufacturing	1260	6.30	12.60
46	Poultry processing	1490	7.45	14.90
47	Seafood product preparation and packaging	1260	6.30	12.60
48	Bread and bakery product manufacturing	892	4.46	8.92
49	Cookie, cracker, and pasta manufacturing	1060	5.30	10.60
50	Tortilla manufacturing	1180	5.90	11.80
51	Snack food manufacturing	1010	5.05	10.10
52	Coffee and tea manufacturing	913	4.56	9.13
53	Flavoring syrup and concentrate manufacturing	395	1.98	3.95
54	Seasoning and dressing manufacturing	1060	5.30	10.60

55	All other food manufacturing	1160	5.80	11.60
56	Soft drink and ice manufacturing	940	4.70	9.40
57	Breweries	866	4.33	8.66
58	Wineries	609	3.04	6.09
59	Distilleries	392	1.96	3.92
60	Fiber, yarn, and thread mills	1670	8.35	16.70
61	Broad woven fabric mills	1270	6.35	12.70
62	Narrow fabric mills and schiffli machine embroidery	894	4.47	8.94

63	Nonwoven fabric mills	1210	6.05	12.10
64	Knit fabric mills	1190	5.95	11.90
65	Textile and fabric finishing mills	1130	5.65	11.30
66	Fabric coating mills	1040	5.20	10.40
67	Carpet and rug mills	1170	5.85	11.70
68	Curtain and linen mills	804	4.02	8.04
69	Textile bag and canvas mills	570	2.85	5.70
70	All other textile product mills	951	4.76	9.51
71	Apparel knitting mills	677	3.39	6.77
72	Cut and sew apparel contractors	384	1.92	3.84
73	Men's and boys' cut and sew apparel manufacturing	487	2.44	4.87
74	Women's and girls' cut and sew apparel manufacturing	566	2.83	5.66
75	Other cut and sew apparel manufacturing	509	2.55	5.09
76	Apparel accessories and other apparel manufacturing	736	3.68	7.36
77	Leather and hide tanning and finishing	2440	12.20	24.40
78	Footwear manufacturing	846	4.23	8.46
79	Other leather and allied product manufacturing	851	4.26	8.51
80	Sawmills and wood preservation	735	3.68	7.35
81	Reconstituted wood product manufacturing	1350	6.75	13.50
82	Wood windows and doors and millwork	595	2.98	5.95
83	Wood container and pallet manufacturing	651	3.25	6.51
84	Manufactured home (mobile home) manufacturing	703	3.52	7.03
85	Prefabricated wood building manufacturing	535	2.68	5.35
86	All other miscellaneous wood product manufacturing	629	3.14	6.29
87	Pulp mills	1710	8.55	17.10
88	Paper mills	1520	7.60	15.20
89	Paperboard mills	1940	9.70	19.40
90	Paperboard container manufacturing	1040	5.20	10.40
91	Stationery product manufacturing	810	4.05	8.10
92	Sanitary paper product manufacturing	974	4.87	9.74
93	All other converted paper product manufacturing	900	4.50	9.00
94	Printing	546	2.73	5.46
95	Support activities for printing	358	1.79	3.58
96	Petroleum refineries	2790	13.95	27.90
97	Asphalt paving mixture and block manufacturing	1670	8.35	16.70

98	Asphalt shingle and coating materials manufacturing	1160	5.80	11.60
99	Petroleum lubricating oil and grease manufacturing	1840	9.20	18.40
100	All other petroleum and coal products manufacturing	2750	13.75	27.50
101	Petrochemical manufacturing	2920	14.60	29.20
102	Industrial gas manufacturing	5510	27.55	55.10
103	Synthetic dye and pigment manufacturing	1890	9.45	18.90
104	Alkalies and chlorine manufacturing	3500	17.50	35.00
105	Carbon black manufacturing	4070	20.35	40.70
106	All other basic inorganic chemical manufacturing	2180	10.90	21.80
107	Other basic organic chemical manufacturing	2720	13.60	27.20
108	Plastics material and resin manufacturing	2510	12.55	25.10
109	Synthetic rubber manufacturing	1880	9.40	18.80
110	Artificial and synthetic fibers and filaments	1760	8.80	17.60
111	Fertilizer manufacturing	6620	33.10	66.20
112	Pesticide and other agricultural chemical manufacturing	945	4.73	9.45
113	Medicinal and botanical manufacturing	442	2.21	4.42
114	Pharmaceutical preparation manufacturing	336	1.68	3.36
115	In-vitro diagnostic substance manufacturing	348	1.74	3.48
116	Biological product (except diagnostic) manufacturing	306	1.53	3.06
117	Paint and coating manufacturing	1070	5.35	10.70
118	Adhesive manufacturing	1210	6.05	12.10
119	Soap and cleaning compound manufacturing	812	4.06	8.12
120	Toilet preparation manufacturing	591	2.96	5.91
121	Printing ink manufacturing	1200	6.00	12.00
122	Plastics packaging materials and unlaminated	1290	6.45	12.90
123	Unlaminated plastics profile shape manufacturing	1080	5.40	10.80
124	Plastics pipe and pipe fitting manufacturing	1420	7.10	14.20
125	Laminated plastics plate, sheet (except packaging	1070	5.35	10.70
126	Polystyrene foam product manufacturing	1250	6.25	12.50
127	Urethane and other foam product (except polyster	1140	5.70	11.40
128	Plastics bottle manufacturing	1390	6.95	13.90
129	Tire manufacturing	1030	5.15	10.30
130	Rubber and plastics hoses and belting manufacturing	894	4.47	8.94

131	Other rubber product manufacturing	911	4.56	9.11
132	Flat glass manufacturing	2050	10.25	20.50
133	Other pressed and blown glass and glassware ma	1230	6.15	12.30
134	Glass container manufacturing	1550	7.75	15.50
135	Glass product manufacturing made of purchased	946	4.73	9.46
136	Cement manufacturing	11600	58.00	116.00
137	Ready-mix concrete manufacturing	2740	13.70	27.40
138	Concrete pipe, brick, and block manufacturing	1920	9.60	19.20
139	Other concrete product manufacturing	1250	6.25	12.50
140	Abrasive product manufacturing	735	3.68	7.35
141	Cut stone and stone product manufacturing	624	3.12	6.24
142	Ground or treated mineral and earth manufacturing	1410	7.05	14.10
143	Mineral wool manufacturing	1380	6.90	13.80
144	Miscellaneous nonmetallic mineral products	2220	11.10	22.20
145	Iron and steel mills and ferroalloy manufacturing	2030	10.15	20.30
146	Steel product manufacturing from purchased steel	2030	10.15	20.30
147	Secondary smelting and alloying of aluminum	3490	17.45	34.90
148	Primary smelting and refining of copper	1260	6.30	12.60
149	Primary smelting and refining of nonferrous me	2340	11.70	23.40
150	Copper rolling, drawing, extruding and alloying	906	4.53	9.06
151	Nonferrous metal (except copper and aluminum)	1070	5.35	10.70
152	Ferrous metal foundries	1060	5.30	10.60
153	Nonferrous metal foundries	1180	5.90	11.80
154	Custom roll forming	1510	7.55	15.10
155	Plate work and fabricated structural product m	964	4.82	9.64
156	Ornamental and architectural metal products ma	873	4.37	8.73
157	Power boiler and heat exchanger manufacturing	787	3.94	7.87
158	Metal tank (heavy gauge) manufacturing	945	4.73	9.45
159	Metal can, box, and other metal container	1240	6.20	12.40
160	Hardware manufacturing	640	3.20	6.40
161	Spring and wire product manufacturing	926	4.63	9.26
162	Machine shops	526	2.63	5.26
163	Turned product and screw, nut, and bolt manufacturing	707	3.54	7.07
164	Coating, engraving, heat treating and allied a	1140	5.70	11.40
165	Plumbing fixture fitting and trim manufacturing	570	2.85	5.70
166	Ball and roller bearing manufacturing	711	3.56	7.11

167	Fabricated pipe and pipe fitting manufacturing	937	4.69	9.37
168	Farm machinery and equipment manufacturing	650	3.25	6.50
169	Lawn and garden equipment manufacturing	611	3.06	6.11
170	Construction machinery manufacturing	651	3.26	6.51
171	Mining and oil and gas field machinery manufacturing	739	3.70	7.39
172	Plastics and rubber industry machinery manufacturing	588	2.94	5.88
173	Semiconductor machinery manufacturing	483	2.42	4.83
174	Optical instrument and lens manufacturing	438	2.19	4.38
175	Photographic and photocopying equipment manufacturing	623	3.12	6.23
176	Other commercial and service industry machinery	533	2.67	5.33
177	Heating equipment (except warm air furnaces) m	660	3.30	6.60
178	Air conditioning, refrigeration, and warm air	581	2.91	5.81
179	Industrial mold manufacturing	659	3.30	6.59
180	Special tool, die, jig, and fixture manufacturing	635	3.18	6.35
181	Cutting tool and machine tool accessory manufacturing	593	2.97	5.93
182	Turbine and turbine generator set units manufacturing	398	1.99	3.98
183	Speed changer, industrial high-speed drive, an	557	2.79	5.57
184	Mechanical power transmission equipment manufacturing	676	3.38	6.76
185	Other engine equipment manufacturing	644	3.22	6.44
186	Pump and pumping equipment manufacturing	563	2.82	5.63
187	Air and gas compressor manufacturing	564	2.82	5.64
188	Material handling equipment manufacturing	747	3.74	7.47
189	Power-driven handtool manufacturing	575	2.88	5.75
190	Packaging machinery manufacturing	453	2.27	4.53
191	Industrial process furnace and oven manufacturing	504	2.52	5.04
192	Electronic computer manufacturing	284	1.42	2.84
193	Computer storage device manufacturing	370	1.85	3.70
194	Telephone apparatus manufacturing	316	1.58	3.16
195	Broadcast and wireless communications equipment	322	1.61	3.22
196	Other communications equipment manufacturing	342	1.71	3.42
197	Audio and video equipment manufacturing	549	2.75	5.49
198	Electron tube manufacturing	712	3.56	7.12
199	Bare printed circuit board manufacturing	572	2.86	5.72

200	Semiconductor and related device manufacturing	603	3.02	6.03
201	Electronic connector manufacturing	586	2.93	5.86
202	Printed circuit assembly (electronic assembly)	400	2.00	4.00
203	Other electronic component manufacturing	454	2.27	4.54
204	Electromedical and electrotherapeutic apparatus	356	1.78	3.56
205	Search, detection, and navigation instruments	309	1.55	3.09
206	Automatic environmental control manufacturing	447	2.24	4.47
207	Industrial process variable instruments manufacturing	440	2.20	4.40
208	Totalizing fluid meters and counting devices m	458	2.29	4.58
209	Electricity and signal testing instruments man	285	1.43	2.85
210	Analytical laboratory instrument manufacturing	335	1.68	3.35
211	Irradiation apparatus manufacturing	385	1.93	3.85
212	Magnetic and optical recording media manufacturing	533	2.67	5.33
213	Electric lamp bulb and part manufacturing	494	2.47	4.94
214	Lighting fixture manufacturing	558	2.79	5.58
215	Small electrical appliance manufacturing	570	2.85	5.70
216	Household cooking appliance manufacturing	782	3.91	7.82
217	Household refrigerator and home freezer manufacturing	776	3.88	7.76
218	Household laundry equipment manufacturing	706	3.53	7.06
219	Other major household appliance manufacturing	655	3.28	6.55
220	Power, distribution, and specialty transformer	813	4.07	8.13
221	Motor and generator manufacturing	660	3.30	6.60
222	Switchgear and switchboard apparatus manufacturing	423	2.12	4.23
223	Relay and industrial control manufacturing	338	1.69	3.38
224	Storage battery manufacturing	1040	5.20	10.40
225	Primary battery manufacturing	553	2.77	5.53
226	Communication and energy wire and cable manufacturing	762	3.81	7.62
227	Wiring device manufacturing	683	3.42	6.83
228	Carbon and graphite product manufacturing	1230	6.15	12.30
229	All other miscellaneous electrical equipment a	380	1.90	3.80
230	Automobile manufacturing	563	2.82	5.63
231	Light truck and utility vehicle manufacturing	603	3.02	6.03
232	Heavy duty truck manufacturing	682	3.41	6.82

233	Motor vehicle body manufacturing	570	2.85	5.70
234	Truck trailer manufacturing	764	3.82	7.64
235	Motor home manufacturing	585	2.93	5.85
236	Travel trailer and camper manufacturing	764	3.82	7.64
237	Motor vehicle parts manufacturing	757	3.79	7.57
238	Aircraft manufacturing	370	1.85	3.70
239	Aircraft engine and engine parts manufacturing	352	1.76	3.52
240	Other aircraft parts and auxiliary equipment m	511	2.56	5.11
241	Guided missile and space vehicle manufacturing	297	1.49	2.97
242	Railroad rolling stock manufacturing	504	2.52	5.04
243	Ship building and repairing	428	2.14	4.28
244	Boat building	532	2.66	5.32
245	Motorcycle, bicycle, and parts manufacturing	760	3.80	7.60
246	Military armored vehicle, tank, and tank compo	535	2.68	5.35
247	All other transportation equipment manufacturing	640	3.20	6.40
248	Wood kitchen cabinet and countertop manufacturing	520	2.60	5.20
249	Upholstered household furniture manufacturing	574	2.87	5.74
250	Nonupholstered wood household furniture manufacturing	491	2.46	4.91
251	Institutional furniture manufacturing	647	3.24	6.47
252	Office furniture and custom architectural wood	464	2.32	4.64
253	Showcase, partition, shelving, and locker manufacturing	892	4.46	8.92
254	Mattress manufacturing	536	2.68	5.36
255	Blind and shade manufacturing	709	3.55	7.09
256	Laboratory apparatus and furniture manufacturing	414	2.07	4.14
257	Surgical and medical instrument manufacturing	314	1.57	3.14
258	Surgical appliance and supplies manufacturing	393	1.97	3.93
259	Dental equipment and supplies manufacturing	636	3.18	6.36
260	Ophthalmic goods manufacturing	323	1.63	3.23
261	Dental laboratories	271	1.36	2.71
262	Jewelry and silverware manufacturing	746	3.73	7.46
263	Sporting and athletic goods manufacturing	613	3.07	6.13
264	Doll, toy, and game manufacturing	581	2.91	5.81
265	Office supplies (except paper) manufacturing	535	2.68	5.35
266	Sign manufacturing	564	2.82	5.64
267	Gasket, packing, and sealing device manufacturing	308	1.54	3.08

268	Musical instrument manufacturing	308	1.54	3.08
269	Broom, brush, and mop manufacturing	580	2.90	5.80
270	Wholesale trade	192	0.96	1.92
271	Air transportation	1980	9.90	19.80
272	Rail transportation	1200	6.00	12.00
273	Water transportation	2780	13.90	27.80
274	Truck transportation	1400	7.00	14.00
275	Transit and ground passenger transportation	1870	9.35	18.70
276	Pipeline transportation	4400	22.00	44.00
277	Postal service	256	1.28	2.56
278	Couriers and messengers	1230	6.15	12.30
279	Warehousing and storage	483	2.42	4.83
280	Newspaper publishers	317	1.59	3.17
281	Periodical publishers	272	1.36	2.72
282	Book publishers	213	1.07	2.13
283	Software publishers	101	0.51	1.01
284	Motion picture and video industries	144	0.72	1.44
285	Sound recording industries	241	1.2`	2.41
286	Radio and television broadcasting	176	0.88	1.76
287	Cable and other subscription programming	182	0.91	1.82
288	Internet publishing and broadcasting	238	1.19	2.38
289	Telecommunications	213	1.07	2.13
290	Internet service providers and web search port	172	0.86	1.72
291	Data processing, hosting, and related services	160	0.80	1.60
292	Other information services	225	1.13	2.25
293	Securities, commodity contracts, investments,	100	0.50	1.00
294	Insurance carriers	66.2	0.33	0.66
295	Insurance agencies, brokerages, and related ac	117	0.59	1.17
296	Funds, trusts, and other financial vehicles	97.9	0.49	0.98
297	Real estate	285	1.43	2.85
298	Automotive equipment rental and leasing	137	0.69	1.37
299	Video tape and disc rental	439	2.20	4.39
300	Commercial and industrial machinery and equipment	245	1.23	2.45
301	Lessors of nonfinancial intangible assets	175	0.88	1.75
302	Legal services	98.9	0.49	0.99
303	Accounting, tax preparation, bookkeeping, and	118	0.59	1.18

304	Architectural, engineering, and related services	186	0.93	1.86
305	Specialized design services	155	0.78	1.55
306	Custom computer programming services	183	0.92	1.83
307	Computer systems design services	173	0.87	1.73
308	Management, scientific, and technical consulting	129	0.65	1.29
309	Scientific research and development services	346	1.73	3.46
310	Advertising and related services	239	1.19	2.39
311	Photographic services	233	1.17	2.33
312	Veterinary services	294	1.47	2.94
313	Management of companies and enterprises	170	0.85	1.70
314	Office administrative services	159	0.79	1.59
315	Facilities support services	236	1.18	2.36
316	Employment services	88.1	0.44	0.88
317	Business support services	186	0.93	1.86
318	Travel arrangement and reservation services	245	1.23	2.45
319	Investigation and security services	159	0.79	1.59
320	Services to buildings and dwellings	491	2.46	4.91
321	Other support services	237	1.19	2.37
322	Waste management and remediation services	2570	12.85	25.70
323	Elementary and secondary schools	374	1.87	3.74
324	Home health care services	235	1.18	2.35
325	Hospitals	366	1.83	3.66
326	Nursing and residential care facilities	366	1.83	3.66
327	Community food, housing, and other relief services	325	1.63	3.25
328	Child day care services	309	1.55	3.09
329	Performing arts companies	164	0.82	1.64
330	Spectator sports	223	1.12	2.23
331	Independent artists, writers, and performers	91.6	0.46	0.92
332	Museums, historical sites, zoos, and parks	496	2.48	4.96
333	Fitness and recreational sports centers	566	2.83	5.66
334	Bowling centers	791	3.96	7.91
335	Food services and drinking places	580	2.90	5.80
336	Car washes	569	2.85	5.69
337	Electronic and precision equipment repair and	190	0.95	1.90
338	Commercial and industrial machinery and equipment	263	1.32	2.63
339	Personal and household goods repair and	306	1.53	3.06

	maintenance			
340	Personal care services	284	1.42	2.84
341	Death care services	445	2.23	4.45
342	Dry-cleaning and laundry services	323	1.62	3.23
343	Other personal services	220	1.10	2.20
344	Religious organizations	176	0.88	1.76
345	Private households	0	0.00	0.00
346	Oilseed farming	3030	15.15	30.30
347	Grain farming	4470	22.35	44.70
348	Fruit farming	1370	6.85	13.70
349	Sugarcane and sugar beet farming	2380	11.90	23.80
350	All other crop farming	2530	12.65	25.30
351	Cattle ranching and farming	7750	38.75	77.50
352	Animal production, except cattle and poultry a	3620	18.10	36.20
353	Forest nurseries, forest products, and timber	1170	5.85	11.70
354	Gold, silver, and other metal ore mining	1700	8.50	17.00
355	Support activities for other mining	977	4.89	9.77
356	Soybean and other oilseed processing	2550	12.75	25.50
357	Sugar cane mills and refining	2270	11.35	22.70
358	Fluid milk and butter manufacturing	2280	11.40	22.80
359	Animal (except poultry) slaughtering, rendering	4090	20.45	40.90
360	Tobacco product manufacturing	348	1.74	3.48
361	Veneer and plywood manufacturing	777	3.89	7.77
362	Engineered wood member and truss manufacturing	522	2.61	5.22
363	Coated and laminated paper, packaging paper an	896	4.48	8.96
364	All other paper bag and coated and treated pap	965	4.83	9.65
365	All other chemical product and preparation man	1080	5.40	10.80
366	Other plastics product manufacturing	904	4.52	9.04
367	Pottery, ceramics, and plumbing fixture manufacturing	1080	5.40	10.80
368	Brick, tile, and other structural clay product	2010	10.05	20.10
369	Clay and nonclay refractory manufacturing	1290	6.45	12.90
370	Lime and gypsum product manufacturing	5320	26.60	53.20
371	Alumina refining and primary aluminum production	3340	16.70	33.40
372	Aluminum product manufacturing from purchased	1560	7.80	15.60
373	All other forging, stamping, and sintering	1490	7.45	14.90

374	Crown and closure manufacturing and metal stamp	1030	5.15	10.30
375	Cutlery, utensil, pot, and pan manufacturing	701	3.51	7.01
376	Handtool manufacturing	782	3.91	7.82
377	Valve and fittings other than plumbing	579	2.89	5.79
378	Ammunition manufacturing	543	2.72	5.43
379	Arms, ordnance, and accessories manufacturing	449	2.25	4.49
380	Other fabricated metal manufacturing	839	4.19	8.39
381	Other industrial machinery manufacturing	633	3.17	6.33
382	Vending, commercial, industrial, and office ma	567	2.84	5.67
383	Air purification and ventilation equipment man	653	3.27	6.53
384	Metal cutting and forming machine tool manufacturing	546	2.73	5.46
385	Rolling mill and other metalworking machinery	496	2.48	4.96
386	Other general purpose machinery manufacturing	644	3.22	6.44
387	Fluid power process machinery	602	3.01	6.02
388	Computer terminals and other computer peripherals	362	1.81	3.62
389	Electronic capacitor, resistor, coil, transformers	609	3.05	6.09
390	Watch, clock, and other measuring and controlling	371	1.86	3.71
391	Software, audio, and video media reproducing	565	2.83	5.65
392	Propulsion units and parts for space vehicle	297	1.49	2.97
393	Metal and other household furniture	810	4.05	8.10
394	Wood television, radio, and sewing machine cab	464	2.32	4.64
395	All other miscellaneous manufacturing	617	3.09	6.17
396	Scenic and sightseeing transportation	505	2.53	5.05
397	Retail trade	265	1.33	2.65
398	Directory, mailing list, and other publishers	239	1.19	2.39
399	Nondepository credit intermediation and relate	110	0.55	1.10
400	Monetary authorities and depository credit	72.6	0.37	0.73
401	General and consumer goods rental except video	230	1.15	2.30
402	Other computer related services, including facilities	132	0.66	1.32
403	Environmental and other technical consulting services	143	0.72	1.43
404	All other miscellaneous professional, scientific services	117	0.59	1.17
405	Junior colleges, colleges, and universities	768	3.84	7.68
406	Other educational services	194	0.97	1.94
407	Offices of physicians, dentists, and other health care	157	0.79	1.57

408	Medical and diagnostic labs and outpatient	243	1.22	2.43
409	Individual and family services	253	1.27	2.53
410	Promoters of performing arts and sports	274	1.37	2.74
411	Amusement parks, arcades, and gambling industry	394	1.97	3.94
412	Other amusement and recreation industries	671	3.36	6.71
413	Hotels and motels, including casino hotels	559	2.79	5.59
414	Other accommodations	565	2.83	5.65
415	Automotive repair and maintenance	328	1.64	3.28
416	Grant making, giving and social advocacy organization	242	1.21	2.42
417	Civic, social, professional and similar organization	398	1.99	3.98
418	Services	382	1.91	3.82

APPENDIX F: MATLAB CODE FOR PART II'S CAP-AND-TRADE SIMULATION

Utility Function

```
% This is the utiltiy function for direct translog This functin returns
the
% utility value for given set of demand quantities

function u=udtl(x)
u=0;

alpha=[-0.0597591
-0.1212314
-0.0282617
-0.0168997
-0.0694104
-0.0143849
-0.5702781
-0.1387694
0.0189947];

gama=[-0.0012296 0.0005823   0.0000589   0.0000533   0.0003612   0.0009997
      0.0007319   0.0000206   0.002714
0.0005823   -0.0038317 0.000124    0.0001264   0.0006196   0.0043796
      0.0023132   -0.00005    0.0072546
0.0000589   0.000124    -0.0011317 -0.0000267 0.0000309   0.0005963
      0.0002963   0.0000187   0.0007273
0.0000533   0.0001264   -0.0000267 -0.00064    0.0003851   0.0004469
      0.0003338   7.49E-06    0.0003174
0.0003612   0.0006196   0.0000309   0.0003851   -0.0061844 0.0043751
      0.0024755   -0.0001531 0.0039921
0.0009997   0.0043796   0.0005963   0.0004469   0.0043751   -0.0644445
      0.0107787   0.0002251   0.0292582
0.0007319   0.0023132   0.0002963   0.0003338   0.0024755   0.0107787   -
0.0069374   -0.0002527 0.03601
0.0000206   -0.00005    0.0000187   7.49E-06    -0.0001531 0.0002251   -
0.0002527   -0.0200727 0.0007281
0.002714    0.0072546   0.0007273   0.0003174   0.0039921   0.0292582
      0.03601     0.0007281   -0.0908828];
 for i=1:9
     for j=1:9
        u = u + 0.5* gama(i,j)*log(x(i))*log(x(j)) ;
     end
 end

 for i=1:9
     u=u+alpha(i)*log(x(i));
```

```
 end
```

Simulation under Carbon Taxes

```
% This estimates demand quantities under taxes
% test data is final
clear all
data=xlsread('input_cappred10_100.xls');
price=data(:,2:10);
[a,b]=size(data);
expn=data(:,11);
fueleco=data(:,18);
options=optimset('fmincon');
options =
optimset(options,'Display','off','MaxFunEvals',4000,'MaxIter',600,'TolFun'
,1e-8,'TolX',1e-8,'TolCon',1e-10);

i=1;
%mini=[10 10 0.1 10 100 100 0.1 2000 2000]';
mini=[0.1 100 0.1 10 100 100 0.1 2000 2000]';
%2max=[609.9224 6722.2 1013.299 3008.2 799.759 10049.91 511.5 51888.6
69876.4]';
%maxi=[353 20000 1000 3008 88496 19099 4500 3808114 277277]';
%maxi=[50 20000 20 10000 36000 12049.91 50 100888.6 100876.4]';
%maxi=[70 24000 30 18000 36000 12049.91 2000 320000 70000]';
maxi=[2 40000 2 18000 70000 30049.91 800 350000 180000]';
avgiter=[];

clear p m ;
avgitert=[];
 % 50ratio=[1.340 1.315 1.001 1.058 1.310 1.045 1.023 1 1];
 ratio=[1.679096728    1.629706899 1.002459582 1.038558493 1.614348939
      1.045499853 1.090779897];

 nprice=price;
 %%%price increasw $50
% nprice(:,1)=nprice(:,1)*1.4515;
% nprice(:,2)=nprice(:,2)*1.4685;
% nprice(:,3)=nprice(:,3)*1.099;
% nprice(:,4)=nprice(:,4)*1.0935;
% nprice(:,5)=nprice(:,5)*1.4395;
% nprice(:,6)=nprice(:,6)*1.0775;
% nprice(:,7)=nprice(:,7)*1.26;
% nprice(:,8)=nprice(:,8)*1.004;
% nprice(:,9)=nprice(:,9)*1.0191;

%%%%%%%%%price increase $100
nprice(:,1)=nprice(:,1)*1.914;
```

```
nprice(:,2)=nprice(:,2)*1.937;
nprice(:,3)=nprice(:,3)*1.198;
nprice(:,4)=nprice(:,4)*1.187;
nprice(:,5)=nprice(:,5)*1.99;
nprice(:,6)=nprice(:,6)*1.1555;
nprice(:,7)=nprice(:,7)*1.341;
nprice(:,8)=nprice(:,8)*1.0081;
nprice(:,9)=nprice(:,9)*1.0383;
avgitert=[];

for k=1:25

for i=1:a
    x=[mini+(maxi-mini).*rand(9,1)] ;
 gh=[k i]
p=nprice(i,:);
m=expn(i);
z=eye(9);
z=-1*z;
p=[p;z];
%m=[m;-0.1;-0.1;-0.1;-0.1;-0.1;-0.1;-0.1;-0.1;-0.1];
m=[m;-10;-1000;-0.1;-10;-1000;-2000;-10;-2000;-3000];
[x,fval,exitflag]=fmincon(@udtl,x,p,m,[],[],[],[],[],options);
xpredt(i,1:9,k)=x;
mb=expn(i);
xpredt(i,10,k)=mb;
p=nprice(i,:);
xpredt(i,11,k)=p*x;
xpredt(i,12,k)=-fval;
xpredt(i,13,k)=exitflag;
xpredt(i,14,k)=fueleco(i);
avg=mean(xpredt(:,:,k));
end
avgitert=[avgitert;avg]
end

for i=1:a
    [mxpred,index]=max(xpredt(i,12,:));
    kkkk(i,:)=xpredt(i,:,index);
end
xlswrite('taxpred_100',kkkk);
```

Cap-and-Trade SImulation

```
%This is for cap and trade,

clear all
data=xlsread('input_cappred10_100_CT.xls');
price=data(:,2:10);
```

```
cap=xlsread('cappred_15_100.xls');
%tax=xlsread('taxxpred_100_new.xls');
%base=xlsread('pred_base_new.xls');
options=optimset('fmincon');
options =
optimset(options,'Display','off','MaxFunEvals',4000,'MaxIter',600,'TolFun'
,1e-8,'TolX',1e-8);
[e,f]=size(data);
%price of carbon in the market change this for budgets
pcarbon=100/2204;
caplimit = 15;

hhs=data(:,12);
fueleco=data(:,18);
mini=[0.1 100 0.1 10 100 100 0.1 2000 2000]';
%max=[609.9224 6722.2 1013.299 3008.2 799.759 10049.91 511.5 51888.6
69876.4]';
maxi=[2 40000 2 18000 70000 30049.91 800 350000 180000]';


%price increases $50
% price(:,1)=price(:,1)*1.4515;
% price(:,2)=price(:,2)*1.4685;
% price(:,3)=price(:,3)*1.099;
% price(:,4)=price(:,4)*1.0935;
% price(:,5)=price(:,5)*1.4395;
% price(:,6)=price(:,6)*1.0775;
% price(:,7)=price(:,7)*1.26;
% price(:,8)=price(:,8)*1.004;
% price(:,9)=price(:,9)*1.0191;

%price increases $100
% price(:,1)=price(:,1)*1.5729;
% price(:,2)=price(:,2)*1.937;
% price(:,3)=price(:,3)*1.198;
% price(:,4)=price(:,4)*1.187;
% price(:,5)=price(:,5)*1.579;
% price(:,6)=price(:,6)*1.1555;
% price(:,7)=price(:,7)*1.341;
% price(:,8)=price(:,8)*1.0081;
% price(:,9)=price(:,9)*1.0383;


cappred=cap;
count=0;
1
for i=1:e
    i
    mbudget=cappred(i,10);
    cbudget=hhs(i)*2204* caplimit;
    cx=cap(i,14);
    cgas=19.56/fueleco(i);
    c=[120 1.3 0.934 0.3 cgas 1 1 0 0  ];
    if cx<cbudget
```

```
    while abs(cbudget-cx)>10
        count=count+1;
        if cbudget > cx % has extra credits
                mbudget = mbudget+(cbudget-cx)/2*pcarbon; % sells half of
them
                cbudget = cbudget-(cbudget-cx)/2;
                x=[mini+(maxi-mini).*rand(9,1)];
                p=price(i,:);
                z=eye(9);
                z=-1*z;
                pr=[p;z;c];
                m=[mbudget;-10;-1000;-0.1;-10;-1000;-2000;-10;-2000;-
3000;cbudget];

                for k=1:25

                    [x,fval]=fmincon(@udtl,x,pr,m,[],[],[],[],[],options);
                    xpredc(i,1:9,k)=x;
                    mb=mbudget;
                    xpredc(i,10,k)=mbudget;
                    xpredc(i,11,k)=p*x;
                    xpredc(i,12,k)=-fval;
                    xpredc(i,13,k)=cbudget;
                    xpredc(i,14,k)=c*x;
                end
                [mxpred,index]=max(xpredc(i,12,:));
                cappred(i,1:14)=xpredc(i,:,index);
                cx=cappred(i,14);

         % if carbon budget is binding and has extra credits

        end
    end
       elseif cx==cbudget
                 6
                 flag=0;
            while flag==0
            mbudget=mbudget-100;
            cbudget=cbudget+100/pcarbon;

                p=price(i,:);
                z=eye(9);
                z=-1*z;
                pr=[p;z;c];
                m=[mbudget;-10;-1000;-0.1;-10;-1000;-2000;-10;-2000;-
3000;cbudget];
            for k=1:7

                    x=[mini+(maxi-mini).*rand(9,1)];
                    [x,fval]=fmincon(@udtl,x,pr,m,[],[],[],[],[],options);
                    xpredc(i,1:9,k)=x;
                    mb=mbudget;
                    xpredc(i,10,k)=mbudget;
                    xpredc(i,11,k)=p*x;
```

```
                xpredc(i,12,k)=-fval;
                xpredc(i,13,k)=cbudget;
                xpredc(i,14,k)=c*x;
         end
            [mxpred,index]=max(xpredc(i,12,:));
                if mxpred>cappred(i,12)
                    cappred(i,1:14)=xpredc(i,:,index);
                    cx=cappred(i,14);
                else
                    flag=1;
                end
        end

    end
end
    cappred(:,15)=data(:,11); %original budget
    cappred(:,16)=cap(:,14); % original utlity
    xlswrite('captradepred_15_100.xls',cappred);
```

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