ABSTRACT

Title of thesis: VEHICLE DEMAND RESPONSES OF GREEN VEHICLE TAXATION POLICIES AND INCREASED GASOLINE PRICES

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The U.S. Federal Highway Trust Fund has experienced significant shortfalls in revenue. This thesis develops three green transportation financing polices based on the fixed vehicle mileage traveled (VMT) fee concept, and analyzes their impact on revenue generation, congestion management, energy/environmental sustainability, and equity. A regression demand model is developed for the analysis. The financing options are compared against a base-case policy of increasing the Federal gas tax by 10 cents/gallon. The distributional impacts of the proposed policies are similar to that of the existing gas tax; green VMT fees and emissions taxes are more regressive, and nation-wide congestion pricing is relatively more progressive. To consider household vehicle ownership number and type decisions, discrete choice models are used. By combining the two modeling techniques with EPA's Motor Vehicle Emission Simulator, we see as gas prices increase, total VMT and emission levels decrease and households move to more fuel efficient vehicles.

Vehicle Demand Responses of Green Vehicle Taxation Policies
and Increased Gasoline Prices

By

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland at College Park in partial fulfillment
of the requirements for the degree of
Masters of Science
2010

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Table of Contents

List of Figures

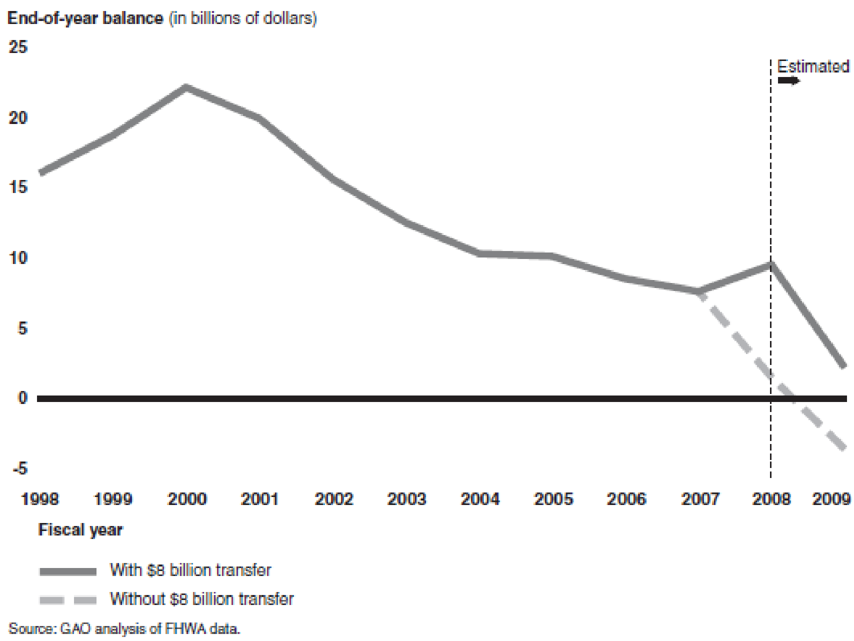
Figure 9. Percent Change in Average Fuel Efficiency at Various Price Scenarios Relative to Current Prices

List of Tables

1. Introduction

Spending to operate, maintain and develop the highway system and road networks in the United States has exceeded Highway Trust Fund (HTF) receipts and threatens its insolvency as shown in Figure 1 below[Error! Bookmark not defined.].

Figure 1: Highway Account Balance, Fiscal Years 1998 through 2009



The current federal gas tax of 18.4 cents per gallon is not indexed to inflation and has remained constant since 1993 while its purchasing power has declined over 35 percent. With increasing corporate average fuel economy standards, a push to become less dependent on foreign oil and the increased use of alternative fuels, consumers are purchasing less gasoline and the HTF will find itself searching for new, sustainable funding sources. The gasoline tax will grow less effective and eventually obsolete. Recent research has explored various policy options to address the shortfall in gas tax revenue, *(1,2,3)* from fixed distance-based user fees to variable fees linked to vehicle fuel economy, emissions (*4,5,6*) or local congestion levels. (*7,8)* Many argue against a fixed vehicle miles traveled (VMT) fee because it penalizes those who have purchased high efficiency vehicles. (*9*) Distance-based user fees will also take time to implement due to policy and engineering constraints. Variable VMT fees are theoretically superior because they can incorporate various externalities (*10,11*) of driving and consequently improve social welfare. Some caution that variable per mile fees should be properly designed or they may not provide sufficient incentives to encourage the purchase of environmentally friendly vehicles. (*12,25)* Other studies have shown that despite gas price increases, vehicle ownership preferences have remained relatively constant. (*13*)

Transportation experts generally agree that today's petroleum based motor vehicle highway system is unsustainable (*14*,*15*) due to air quality issues, climate change concerns, congestion and urban sprawl. Growing energy consumption and pollution in the transportation sector has a distinct spatial and urban dimension. (*16,17*) As urban dwellers acquire more wealth and transportation costs remain low, many households move to the periphery of urban areas, increasing the frequency and distance of car trips. Transportation is one of the leading sources (33.7%) of energy-related greenhouse gas emissions in the United States. (*18*) In order to achieve sustainability, technology, land use planning and financing must be improved. (*19*) Current transportation financing practices, largely based on fuel taxes and vehicle registration fees, do not account for the external costs a driver imposes on the environment or other road users. Optimal first-best pricing to address congestion and environmental externalities is difficult to implement because of its lack of public and political support. (*20,21,22)* Suggested second best pricing schemes include green distance-based user fees, emission taxes, cap and trade, and congestion pricing on selected facilities. (*23*,*24*)

The goal of this thesis is to design and estimate the impact of several innovative green transportation financing policies based on the distance-based user charge concept, (*25,26*) including a green VMT fee based on vehicle fuel efficiency, a distance-based emissions tax, and a mileage-based congestion pricing scheme. These financing options are not proposed to necessarily maximize system-wide social welfare but rather to design practical and feasible financing schemes that (a) can be implemented with a nation-wide or state-wide distance-base user charge system; (*27,28*) (b) meet pre-determined revenue generation goals; (c) significantly improve transportation system efficiency and sustainability by internalizing congestion and environmental externalities; and (d) produce distributional effects that are either acceptable or can be addressed with readily-available policy tools. We also want to explore the effects of increased fuel costs on household vehicle ownership patterns.

The methodology employs a regression-based demand model that estimates the heterogeneous elasticity of VMT for different population groups in response to the proposed green transportation financing policies. (*29*) The impacts of these policies with regard to revenue generation, VMT, congestion, sustainability, and equity are then evaluated based on model outputs at the national and state levels. (*30*) Distributional effects are measured for each population group (defined by income, geographical location, ethnicity, etc.) as changes in consumer surplus (*31,32*), VMT, gasoline consumption, total revenue collected by federal and state agencies, and overall welfare changes. Through discrete choice analysis, we analyze how increased fuel prices will alter vehicle ownership number and type decisions. Combining this with the regression demand model and MOVES data, we measure the change in VMT and vehicle GHG and pollutant emissions. It is the author's hope that with an improved understanding of the effectiveness and equity of transportation financing options, informed decisions can be made toward a green and sustainable transportation system. (*33*)

2. Background and Literature Review

2.1 Surface Transportation Financing

Over the past few decades the Congressional Budget Office (CBO) has observed the revenue stream of the HTF and assessed its ability to fund the construction of new highways as well as maintain existing infrastructure. The CBO's conclusions paint an ominous picture of escalating construction costs, accumulating repairs, and declining revenue sources as vehicle fuel efficiency increases. The Highway Trust Fund faces an insolvency crisis and the federal gas tax cannot sufficiently support the program's spending.

The American Association of State Highway and Transportation Officials (AASHTO) produced the report *The Bottom Line Technical Report: Highway and Public Transportation Nation and State Investment Needs*, which identifies the nation's many challenges in investing in its infrastructure: declining revenue, higher capital construction costs, higher fuel costs, and a weak economy. The report predicts the needed spending per year based on three scenarios. The first scenario is a 1.4 percent annual growth rate. The first scenario would require an investment of $166.8 billion (2006 dollars) a year from all levels of government to close the investment gap for highways and bridges. The second scenario considered is a VMT growth of just 1 percent mirroring the population growth rate. The second scenario would require an annual investment of $132.4 billion (2006 dollars) per year from all levels of government to close the gap. Considering inflation, those values are $186.6 billion and $148.1 billion (in 2008 dollars) respectively. An important baseline to consider is to maintain the current physical condition and performance of the system. While this is not a useful goal for a system that already is unable to provide for an aging infrastructure system, it establishes the minimum investment required to prevent further degradation. The value determined in the AASHTO report for this baseline condition (a third scenario) is $93.3 billion per year. The current level of spending is $68 billion per year. These projections only consider investments in highways and bridges while there is no consideration for public transit, which is also funded by fuel taxes through the HTF.

Congress created Finance and Revenue Commissions under the Safe, Accountable, Flexible, Efficient Transportation Equity Act- A Legacy of Users (SAFETEA_LU) to assess the revenue and financing of infrastructure. Studies conducted by the Finance Commission showed that travel demand growth rates have exceeded population growth rates in part due to a shift to single occupant vehicles, and also due to increases in trip making, trip length and a switch to the auto from other modes of transportation. The deterioration of the road system is not only caused by under investment but also from overuse due to being underpriced. Congestion has a large negative impact on individuals' lives, security and economy including lost time, long queues and wasted fuel. The Revenue Commission analyzed options for both a short and long term perspective. Although alternatives to the gasoline tax must be considered down the road, the federal gas tax presently acts as an attractive source of revenue for four reasons: 1) low administrative and compliance costs, 2) ability to generate substantial amounts of revenue, 3) relative stability and predictability and 4) ease of implementation. They also recommend indexing the tax to inflation to protect its purchasing power. The Finance Commission collaboratively with Transportation Research Board (TRB) and

AASHTO, concluded that the best long term solution for a future federal funding system would be a distance-based "user pay" VMT fee. Because of its many physical and political barriers, the Commission believes this is a medium to long-term solution and does not expect full implementation until the year 2020.

2.2 Addressing Other Driving Externalities

In 1970, the Environmental Protection Agency was given responsibility to regulate motor vehicle pollution and mandated a 90 percent reduction in the emissions of new automobiles. In 1994 the phase-in began for cleaner vehicle standards and technologies required by the 1990 Clean Air Act. According to the EPA, about 20 percent of total CO_2 emissions come from passenger vehicles (18). The Congressional Budget Office analyzed policy options that address greenhouse gases and found that carbon taxes, cap-and-trade legislation and a gas tax increase would result in similar declines in GHGs. (*34,35)* Others suggested policies to lower emissions include providing incentives for newer vehicles, alternative fuel vehicles and hybrids,(*36*) increased emission standards and investment in advanced technology. (*37*) Most transportation related criteria pollutants (PM_{10}, $PM_{2.5}$, VOCs, CO, NO_x and SO_2) have declined since 1990, but carbon dioxide has been on the rise. The transportation sector produced 2.0 billion metric tons of CO_2 equivalent GHGs in 2006 and has grown at a rate of 1.4 percent since 1990. A suggested price of $28 per metric ton of CO_2 emitted would add about 25 cents to the price of a gallon of gasoline. In the short run, CO_2 levels would remain the same but over time would show a 2.5% decline, a relatively small drop due to the low price elasticity of gasoline and the car dependent nature of Americans. Though politicians assume there is much opposition to increased gas taxes, a Mineta Transportation Institute survey of California residents showed that the majority of respondents supported green policies like incentives for less polluting cars, green mileage fees and green vehicle registration. (*38*) Most studies have found, however, that emissions regulations are regressive in nature despite environmental risks disproportionately affecting poorer groups. (*39,40,41)*

Reducing vehicle miles traveled not only results in lowered emissions but also lower congestion levels. (*42*) Many urban areas need stronger pricing strategies to reduce the congestion (*43*) from passenger vehicle use. Most vehicle owners prefer to use personal vehicles to travel since most of the costs are already paid for i.e. ownership, registration, and insurance. With a significant price signal, road users will likely start to reconsider their trip decisions. Urban areas like San Diego, Los Angeles and London have successfully implemented pricing schemes that have reduced vehicle miles driven. (*44,45,46)* Congestion pricing can provide more reliable trip times, better system performance, and substantial revenue gains. (*47,48)* While this thesis will explore a nation-wide congestion pricing scheme based on regional congestion levels, vehicles could also be priced based on specific roads, time of day or vehicle occupancy. (*49*) Other alternatives include a 'cash out' approach to reward those who reduce their vehicle use. (*50*) Some argue that congestion pricing is unjust and tends to penalize lower-income drivers. (*51*) However, the distributional effects of a nation-wide congestion pricing scheme has not been thoroughly studied.

2.3 Previous Studies of Distance-Based Fee Programs

Optimal solutions for road pricing must be both economically efficient and equitable. The current pricing scheme of the fuel tax is suboptimal since it does not reflect many of the externalities of driving like road wear and congestion. It is however the most commonly used distance-based user tax due to its simplicity. Developments in today's Global Positioning Systems (GPS) technology and Automatic Vehicle Identification (AVI) have made distance based user fees a reasonable alternative to the gas tax and viable answer to the concerns of the HTF. Distance-based road user fees were used for many years before gas taxes were enacted in Oregon, New Mexico, and Colorado in 1919, and in a total of 48 U.S. states by 1929 (*52*) Morrison and Small have contributed extensive literature on optimal road user fees in both congested and uncongested situations. Using simulation techniques studies have shown converting from the current fuel tax system to a more efficient VMT fee system would result in welfare gains. (40).

Inequity is a major concern with politicians for increasing the price of driving. Recent road user charge experiments in Hong Kong, Cambridge and central London have demonstrated the importance of pricing scheme design and public acceptance. (*53*) Viegas (*54*) recommends easy-to-understand terms that could serve as targets for mobility managers like increasing the level-of-service. Researchers have also warned against any drastic changes that may disrupt existing balances, believing that policy changes should occur gradually. (*55*)

This brief review reveals that the key externalities of driving not yet internalized include congestion, pollution emissions, and GHG emissions. Externalities due to traffic accidents is partially internalized with user-pay auto insurance programs, (*56*,*57*,*58*,(*59*) Sorenson and Taylor reviewed twenty distance-based user fee programs around the world. These studies include distance-based tolls for large trucks, distance-based user fee proposals, distance-based emission taxes and pay-as-you-drive insurance programs. Economist in general agree that a per mile fee would better capture the marginal costs of drive and so act as a more efficient pricing system.

DeCorla-Souza and Litman also discuss the benefits of distance-based insurance. An optional distance-based insurance program was analyzed by DeCorla-Souza where he estimated its impacts using social cost measurements. A European based organization called PRoGRESS designs and evaluates road pricing schemes in eight urban areas.. They use social equity as the main criterion to evaluate each of their studies.

Previous research by Zhang et al. empirically estimates the use of a distance based road user fee in the state of Oregon. Distributional effects were measured as changes in consumer surplus, fee-collection agency revenue totals and overall welfare change by income and location groups. There are no studies that empirically estimate the use of a per mile fee at the national level though there is literature that looks at a distance based fees as a means of collecting emission taxes. West and Parry and Small conclude that a mileage fee is a better means of estimating optimal emission fees than a gasoline tax. West and Walls and Hanson have found that per mile emission fees are regressive. Lower income groups appear to pay a higher percentage of their income toward fees than do wealthier income groups.

3. Data and Model

3.1 2001 NHTS Regression Analysis

A multiple regression model was developed with household annual miles driven as the dependent variable. The regression model can estimate the overall impact of proposed green transportation financing policies (detailed in Section 4) based on a variety of measures of effectiveness (detailed in Section 5). The policy shift from the existing gasoline tax to distance-based user fees is captured in the "fuel cost per mile" variable in our model. Under the gasoline tax, the fuel cost per mile was calculated as the price of gasoline divided by a vehicle's fuel efficiency. Under the per mile user fees, the gasoline tax was subtracted out and the per-mile charge was added to the total. The model also employs interaction variables between fuel cost per mile and other socio-demographic variables to allow for heterogeneous demand responses by different population groups. There are 20 independent variables in the model, and the dependent variable is the natural log of annual vehicle miles driven at the household level.

The multiple-regression model is specified as follows:

$$M = f\,(P_M, I, SUB, V, L, P_M{*}I, P_M{*}SUB, HH_M) \quad (1)$$

Where M is total annual household miles; P_M is the natural log of fuel cost per mile; I is the natural log of annual household income; and V is the number of household vehicles. The fuel cost per mile variable is a weighted average based on the miles reported for each vehicle a household owns. *SUB*, a dummy variable, is equal to 1 if a household has more than one type of vehicle (e.g. a car and an SUV). As the fuel cost per mile changes for each vehicle, a household with multiple vehicle types will be able to substitute driving between different vehicle types. L is a vector of 3 dummy variables that represents Census Metropolitan Statistical Area Categories (Category 1: large urban area with rail transit; 2: large urban area without rail transit; and 3: small urban area). P_M*I is an interaction term between household income and fuel cost per mile, which allows for different income groups to respond differently to changes in fuel cost including gas tax or VMT fees. P_M*SUB is another interaction term that allows for households with or without multiple vehicle types to respond differently to fuel cost changes. HH_M is a vector of other household characteristics, including number of children, number of workers, number of licensed drivers, age, ethnicity, and gender of the household head, land use density, and transit use. Many of the independent variables are modeled as the natural log of the value. The log-log functional form has been shown to be superior in previous research and would allow easier computation of demand elasticities. Using the log functional form also minimizes the heteroskedasticity of some of the variables, where some variables have different variances. The fuel cost per mile coefficient is expected to be negative, consistent with a downward sloping demand curve for vehicle miles driven. If a household owns more vehicles, it is expected that the household will drive more miles. Households with many types of vehicles are likely to drive more than households that are not able to substitute between vehicles; the *SUB* coefficient is expected to be positive. As the number of children or workers in the household increase, the household is also expected to drive more miles.

To estimate the model, we use the 2001 National Household Travel Survey (NHTS) data with a final sample of 15,902 households from all 50 states and Washington

D.C. The household samples are selected based on the completeness and accuracy of survey responses. Additional information necessary for model estimation such as fuel price is obtained from the Energy Information Administration (EIA). Table 1 shows the results from the 2001 multiple regression model and explains all model variables in detail. The R-squared value for the model is 0.7116, and the adjusted R-squared value 0.7113. Some collinearity was found between variables like driver count, vehicle count and worker count. The multicollinearity among these variables does not reduce the predictive power of the overall model or reliability of the model as a whole, especially with statistically strong variables. Multiple regression models with correlated independent variables may be faulty in their prediction of these individual variables but can still provide a good estimate of the dependent variable.

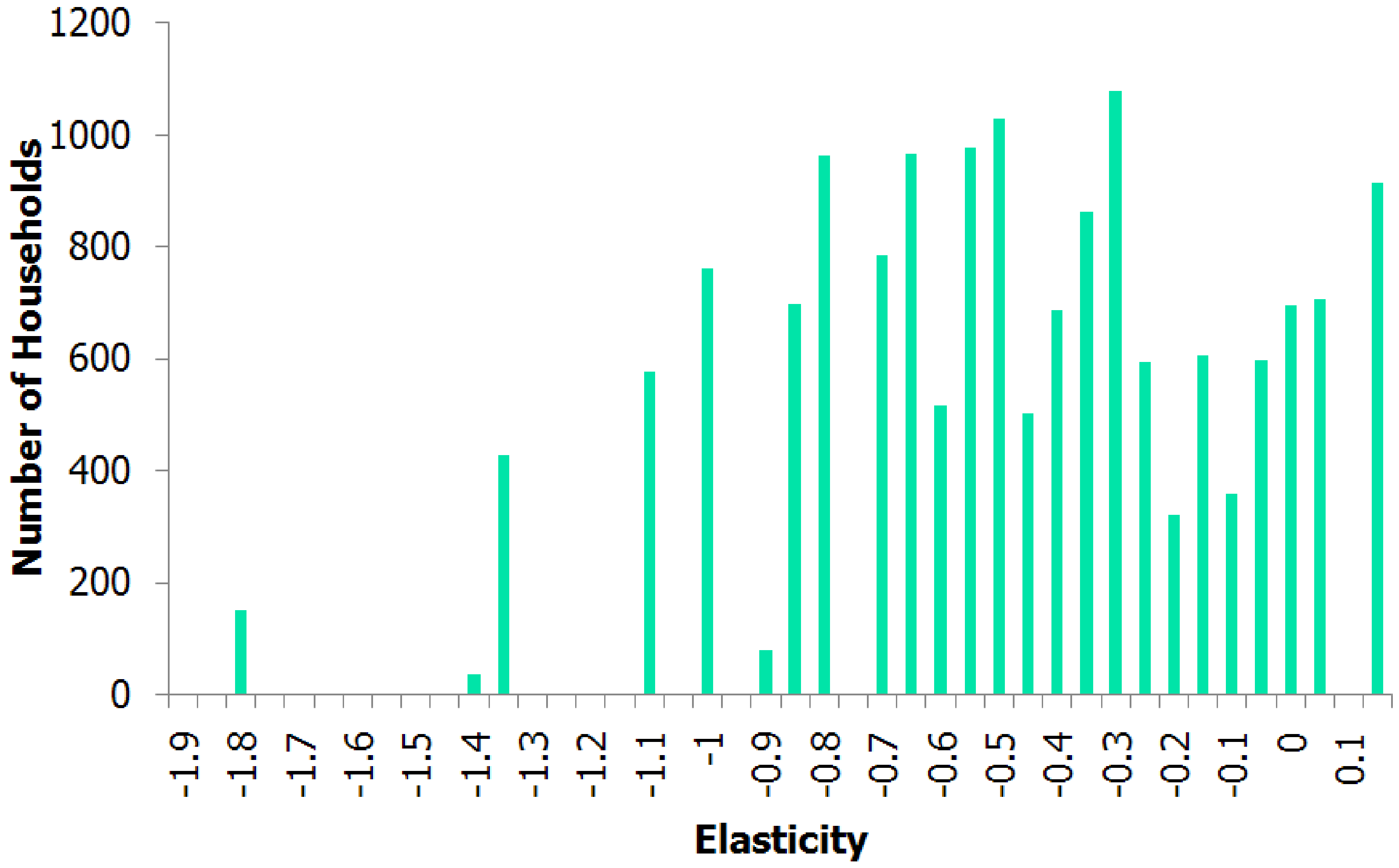
The regression results suggest that as fuel costs rise, households will lower their annual miles driven. Households with more vehicles, workers, and children tend to drive more. Households with a male head drive more than those with a female head. The household demand elasticities (*60*) with respect to fuel costs changes due to financing policy can be computed from the coefficients of fuel cost per mile and the interaction variables. According to the model, the lowest-income households with only one vehicle have the largest sensitivity to policy changes, and would drive almost 1.8% less in response to just 1% increase in fuel cost. The driving behavior of the richest households with multiple vehicle types would not be impacted at all with elasticity close to zero. Some high income households could experience a positive elasticity in

Table 1 Regression Coefficient Estimates and Variable Definitions

Variable	Coefficient Estimate 2001	Coefficient Estimate 2009	Explanation
Fuelcost/mile	-5.111***	-1.226***	Cost of fuel per mile based on current vehicle ownership
Income	1.341***	0.123***	Household income
Income Fuelcost/mile*	0.420***	0.073***	Income multiplied by fuel cost/mile
Substitute Fuelcost/mile*	0.421***	0.406***	Substitute multiplied by fuel cost per mile
Vehicle count	0.746***	1.014***	Number of vehicles owned by the household
Substitute	1.164***	-0.968***	Household's ability to substitute driving between vehicles of differing fuel efficiencies
Male	0.089***	0.058***	If the call respondent at the household is a male
Worker count	0.085***	0.0126***	The total number of workers residing at the household
Driver count	0.102***	0.030***	The total number of drivers residing at the household
Children count	0.039***	0.052***	The total number of children at the household
African American	-0.012	-0.121***	If the call respondent is African American
Asian	-0.094***	-0.110***	If the call respondent is Asian
Hispanic	0.041**	0.012	If the call respondent is Hispanic
Age 16-35	0.398***	0.314***	If the call respondent is between age 16 and 35
Age 36-64	0.266***	0.215***	If the call respondent is between the age 36 and 64
Population density	-0.061***	------	Household census tract population density
MSA category 1	0.016*	-0.025***	Households located in a Metropolitan Statistical Area with >1 million population and access to rail transit
MSA category 2	0.029***	0.032***	Households located in a Metropolitan Statistical Area with >1 million population but no access to rail transit
MSA category 3	-0.025**	-0.017***	Households located in a Metropolitan Statistical Area with a population less than one million people
Transit trips	-0.134***	-0.022***	The number of household public transit trips/day
Constant	-6.924***	8.254***	Constant variable

Italics font indicates the variable is logged. ***, **, and * indicate that the coefficient is statistically significant at 99%, 95% and 90% confidence levels respectively.

Figure 2.Distribution of 2001 Household Demand Elasticity: VMT w.r.t. Driving Cost/Mile



response to less congested road conditions due to the overall reduced demand for driving. Figure 2 plots the distribution of demand elasticities of all households in our sample. The average elasticity is about 0.32, which indicates that if a new financing policy doubles the user-paid cost of driving, total VMT would decrease by 32% for the average household.

This regression-based demand model enabled the computation of changes in VMT, taxes paid, and welfare at the household level in response to green transportation financing policies, which supports the distributional impact analysis. The household-level results were then aggregated to the national and state levels for revenue and welfare analysis in the subsequent sections.

3.2 2009 NHTS Regression Analysis

To combine the analysis of VMT, vehicle ownership, and emissions, we employed the same regression analysis using 2009 NHTS data. The 2001 NHTS did not have sufficient vehicle characteristics data to effectively perform the discrete choice model and using more current data was preferable. The model was formulated similarly with 19 independent variables, and the dependent variable as the natural log of annual vehicle miles driven at the household level.

All the variables used were the same as those used in the 2001 NHTS analysis with the exception of land use density. The 2009 NHTS survey did not collect data for this variable. To estimate the model, we use the 2009 NHTS data with a final sample of 37578 households from all 50 states. The household samples were selected based on the completeness and accuracy of survey responses. Additional information necessary for model estimation such as fuel price was obtained from the Energy Information Administration (EIA). Data from the Tax Foundation provided state gas tax information. Table 1 shows the results from the 2009 multiple regression model and explains all model variables in detail. The R-squared value for the model is 0.6010, and the adjusted R-squared value is 0.6008.

The regression results were very similar. As fuel costs rise, households will lower their annual miles driven. Most variable coefficients follow the same trends as 2001 with the exception of the substitute variable. In 2009 the coefficient for substitute is negative indicating that owning vehicles of different fuel efficiencies leads to fewer annual miles driven. According to the model, the most sensitive household would drive about .66% less in response to a 1% increase in fuel cost. The driving behavior of the least sensitive households would not be impacted at all with elasticity close to zero. Again, some high income households could experience a positive elasticity in response to less congested road conditions due to the overall reduced demand for driving. Figure 3 plots the distribution of demand elasticities of all households in our sample. The average elasticity is about 0.37, which indicates that if a new financing policy doubles the user-paid cost of driving, total VMT would decrease by 37% for the average household.

3.3 Discrete Choice Model

Many past studies have developed discrete-continuous choice models that tie vehicle choice behavior to short term VMT demand response. (*72 ,76,75*) Our analysis of various gas price scenarios will utilize outputs from discrete choice models created by Zhang and Lu. (*74*) The models were originally linked to a regression model and used to determine whether a nonattainment designation in the Congestion Mitigation Air Quality Improvement (CMAQ) program would result in households driving less. CMAQ was introduced by the EPA to assist states and metropolitan areas to improve their air quality by funding transportation projects that reduce the demand for vehicle miles driven. The findings suggested that a nonattainment designation not only showed positive correlation with reduced VMT but also that households transitioned to fewer and more fuel efficient vehicles.

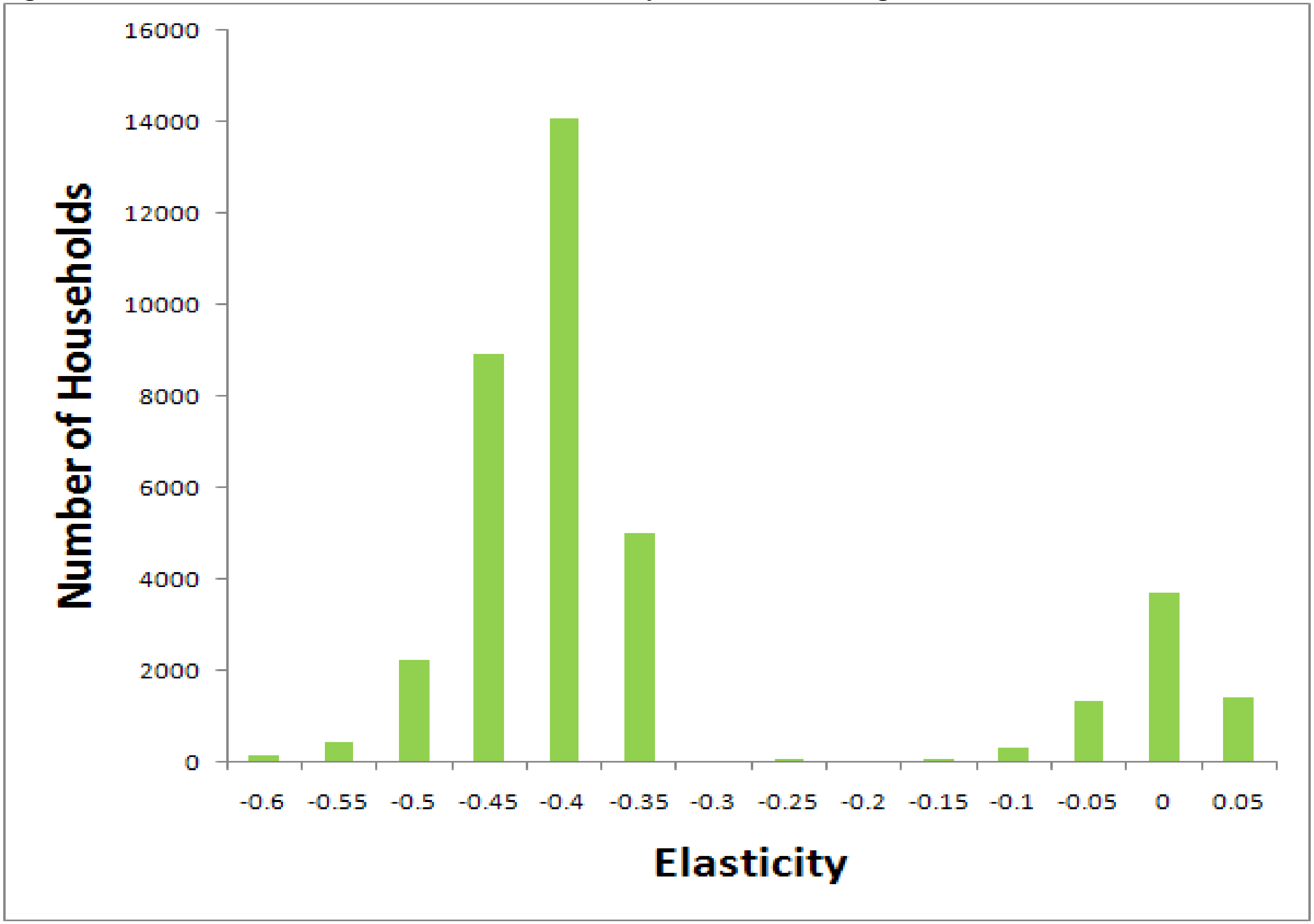
Both vehicle number and type were defined as nested logit models

$$V = f\,(N, M, P_V, P_F, I, U, \mathrm{HH}_\mathrm{V}) \quad (2)$$

$$T = g\,(N, P_{V,T}, V, P_{M,T}, I, U, \mathrm{HH}_\mathrm{T}) \quad (3)$$

where (*V*) is vehicle quantity while (*T*) is vehicle type for one vehicle households and vehicle bundle for multiple vehicle households. Vehicle number decisions (*V*) were based on air quality nonattainment status (*N*), expected vehicle use (*M*), vehicle price (P_V), fuel price (P_F), income (*I*), location (*U*), and other household characteristics (HH_V). This model distinguishes vehicle type (*T*) into seven categories: small car, large car, small SUV, large SUV, small pickup trick, large pickup truck and minivan. For multiple vehicle households, the bundles are defined as groups like small car-large SUV, large car- small SUV, small car-minivan-large pickup truck, etc. Vehicle type (*T*) decisions are based on air quality nonattainment status (*N*), price of vehicles by type ($P_{V,T}$), fuel cost per mile by vehicle type ($P_{M,T}$), income (*I*), location (*U*), and other household characteristics (HH_T). As the number of vehicles increases, the number of bundle types increases exponentially and so this model only estimated results for households with up to four vehicles.

Figure 3. Distribution of 2009 Household Demand Elasticity: VMT w.r.t. Driving Cost/Mile



Vehicle Number Model

Household vehicle characteristics used in the discrete choice models were obtained from the 2009 NHTS while vehicle characteristics (interior room, engine size, vehicle purchase price etc.) for different makes and models were defined by Consumer Reports data. After filtering out households with incomplete data, the final model estimation was based on 37,122 households. The model estimation results are found in Table 2.

Table 2. Household Vehicle Number Choice Model Results

Dependent Variable: Number of Vehicles Households Choose to Own Number of observations: 37122				
	One Vehicle	Two Vehicle	Three Vehicle	Four+ Vehicle
Variable	Coefficient	Coefficient	Coefficient	Coefficient
Constant	-1.7857**	-4.2314**	-6.5754**	-9.4959**
Income	0.0031**	0.0048**	0.0052**	0.0054**
Worker Count	0.4314**	1.1623**	1.6643**	2.1180**
Large Urban	-0.2068**	-0.7471**	-1.1362**	-1.5120**
Small Urban	0.1067*	-0.1961**	-0.5461**	-0.8678**
White	0.5404**	0.7970**	0.5025**	0.4121
Asian	-0.5253**	-0.7526**	-0.8519**	-1.4028**
African American	0.2604	0.0920	-0.3448	-0.9135*
Children/HHSIZE	0.3847**	1.8204**	1.6741**	1.3740**
MALE	0.3258**	0.8109**	0.7398**	0.8417**
Age <35	0.2271**	0.6236**	0.3261**	0.4975*
Age 36~54	0.1722**	0.2147**	0.4368**	0.4875**
Home ownership	1.6165**	2.8679**	3.3428**	3.9284**
Nonattainment	-0.2426**	-0.6977**	-0.9351**	-0.7516**

** and * indicate the coefficient is significant at 95% and 90% confidence levels respectively

The coefficients indicate that higher income households and those with more workers tend to own more vehicles. Urban residents tend to own only one vehicle, likely due to the many transportation options offered in such areas headed by males and those with more children are more likely to own more vehicles. Homeowners and older (between ages 35 and 64) heads of households also tend to own more vehicles.

Vehicle Type Model

With increasing vehicle number, a household's number of options for owning different bundles increases exponentially. One vehicle households have 7 options, two vehicle households 27, three vehicle households 84 and four vehicle households 210. These numbers also represent the number of coefficients that must be estimated for each variable in the different number choice models. If there were 10 variables, 70, 270, 840 and 2100 coefficients would have to be determined for each of the four number choice models respectively. The large sample size (37,122 households) makes calculations for so many scenarios infeasible. Instead a simulation process was used where ten bundle choices were randomly generated for each of the 2+ vehicle households, with one option being the actual chosen alternative. Reducing the choice set to a randomly selected ten should not bias the coefficient estimates.

The model estimation results are found in Table 3.

Table 3. Vehicle Type Choice Model Results for One-Vehicle Households

	Small Car	Large Car	Small SUV	Large SUV	Small Truck	Large Truck
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Constant	-0.8989	0.8598	-1.3606**	-2.8046**	-3.4612**	0.5544
Price*Income	3.61E-09**					
Price	-0.00023**					
Fuel Cost/mile	-0.107*					
Price* (FuelCost/mile)	2.06E-06*					
Safety	.0398					
Interior room*HHSIZE	0.0194**					
Interior room	-0.0279**					
Engine Size	0.0524					
Household Size	1.1177**	1.2964**	1.0859**	0.1305	1.8914**	0.8051**
Male	-0.0648	-0.0908	-0.3712**	0.0954	1.4731**	1.430**
Children Count	0.3657**	-0.0743	0.4254**	0.3044**	-0.2109	0.4442**
Income	0.000015**	-2.47E-06	0.000019*	-0.00003**	1.26E-06	-0.00003**
Large Urban	0.5847**	0.2868*	0.3259	-0.1010	-0.6722**	-0.7203**
Small Urban	0.3864**	0.2596	0.3140**	-0.1713	-0.4549	-0.4044*
Own House	-0.9112	-0.7733	-0.5378**	-0.6561**	-0.9439**	0.5544

** and * indicate the coefficient is significant at 95% and 90% confidence levels respectively

Estimates for multiple vehicle households are not shown due to size constraints but are consistent with Table 3's results. According to the coefficient estimates, households prefer vehicles that are lower priced, safer, more powerful, and lower in operating cost and fuel cost per mile. Lower income households tend to be more sensitive to vehicle price as evidenced by the positive coefficient for the Price*Income interaction variable. The positive coefficient for the Price*FuelCost/Mile interaction variable indicates that those who willingly pay high prices for certain vehicle types are less sensitive to the operating and fuel costs for these kinds of vehicles (e.g. large SUV and large trucks). Vehicle interior room has a very small effect on one person households. As households increase in size, vehicle interior room becomes more significant.

Results show that male household heads and households with more children are more likely to choose trucks and large SUVs. The relationship between income and vehicle type choice is not clear aside from the negative correlation between high income households and large SUVs or large trucks. Urban residents strongly prefer cars while their rural counterparts strongly prefer trucks and large SUVs. Those who are not homeowners tend to select cars. Asian households prefer large cars and large SUVs, while African American households strongly prefer not owning trucks.

3.4 MOVES Emissions Analysis

To determine changes in GHGs and pollutants as a result of the various gas price scenarios, we extracted 2009 emission rates by state using the EPA Motor Vehicle Emission Simulator (MOVES) shown in Tables 4a and b.

Table 4a. MOVES GHG Emission Rates

GHG Emission Rates Tons/Miles			
State	**CO2**	**CO2eq**	**CH4**
ALABAMA	5.63E-04	5.64E-04	2.98E-08
ALASKA	5.78E-04	5.79E-04	3.14E-08
ARIZONA	5.87E-04	5.87E-04	2.95E-08
ARKANSAS	5.49E-04	5.49E-04	2.96E-08
CALIFORNIA	5.78E-04	5.79E-04	2.95E-08
COLORADO	5.73E-04	5.73E-04	3.01E-08
CONNECTICUT	5.76E-04	5.77E-04	2.90E-08
DELAWARE	5.69E-04	5.70E-04	2.99E-08
FLORIDA	6.08E-04	6.09E-04	3.06E-08
GEORGIA	5.64E-04	5.65E-04	3.02E-08
HAWAII	5.87E-04	5.87E-04	2.96E-08
IDAHO	5.58E-04	5.59E-04	2.88E-08
ILLINOIS	5.83E-04	5.83E-04	3.06E-08
INDIANA	5.66E-04	5.66E-04	2.93E-08
IOWA	5.61E-04	5.61E-04	2.92E-08
KANSAS	5.62E-04	5.63E-04	2.96E-08
KENTUCKY	5.57E-04	5.57E-04	2.88E-08
LOUISIANA	5.63E-04	5.63E-04	2.91E-08
MAINE	5.53E-04	5.54E-04	2.86E-08
MARYLAND	5.72E-04	5.72E-04	2.94E-08
MASSACHUSETTS	5.89E-04	5.89E-04	2.98E-08
MICHIGAN	5.76E-04	5.76E-04	3.06E-08
MINNESOTA	5.68E-04	5.69E-04	2.93E-08
MISSISSIPPI	5.48E-04	5.49E-04	2.87E-08
MISSOURI	5.65E-04	5.65E-04	2.97E-08
MONTANA	5.53E-04	5.53E-04	2.99E-08
NEBRASKA	5.63E-04	5.64E-04	2.94E-08
NEVADA	5.74E-04	5.74E-04	3.07E-08
NEW HAMPSHIRE	5.62E-04	5.63E-04	2.89E-08
NEW JERSEY	5.85E-04	5.86E-04	2.99E-08
NEW MEXICO	5.58E-04	5.58E-04	2.93E-08
NEW YORK	5.78E-04	5.79E-04	2.95E-08
NORTH CAROLINA	5.62E-04	5.63E-04	3.00E-08
NORTH DAKOTA	5.57E-04	5.57E-04	2.95E-08
OHIO	5.71E-04	5.71E-04	2.97E-08
OKLAHOMA	5.62E-04	5.63E-04	2.94E-08
OREGON	5.63E-04	5.64E-04	2.91E-08

PENNSYLVANIA	5.70E-04	5.71E-04	2.99E-08
RHODE ISLAND	5.91E-04	5.91E-04	2.99E-08
SOUTH CAROLINA	5.53E-04	5.54E-04	2.98E-08
SOUTH DAKOTA	5.52E-04	5.52E-04	2.89E-08
TENNESSEE	5.68E-04	5.68E-04	2.97E-08
TEXAS	5.77E-04	5.78E-04	3.02E-08
UTAH	5.77E-04	5.77E-04	3.08E-08
VERMONT	5.61E-04	5.61E-04	2.87E-08
VIRGINIA	5.71E-04	5.71E-04	3.02E-08
WASHINGTON	5.76E-04	5.77E-04	3.03E-08
WEST VIRGINIA	5.51E-04	5.52E-04	2.89E-08
WISCONSIN	5.68E-04	5.68E-04	2.97E-08
WYOMING	5.57E-04	5.58E-04	2.90E-08

Table 4b. MOVES Pollutant Emission Rates

Pollutant Emission Rates Tons/Miles						
State	**CO**	**NOx**	**PM10**	**PM2.5**	**TOG**	**VOC**
ALABAMA	1.35E-05	1.77E-06	2.19E-08	2.04E-08	1.07E-06	1.02E-06
ALASKA	2.79E-05	1.98E-06	5.58E-08	5.16E-08	1.50E-06	1.43E-06
ARIZONA	1.29E-05	1.95E-06	1.98E-08	1.85E-08	1.01E-06	9.63E-07
ARKANSAS	1.47E-05	1.75E-06	2.31E-08	2.16E-08	1.06E-06	1.00E-06
CALIFORNIA	1.25E-05	1.69E-06	2.41E-08	2.25E-08	1.04E-06	9.96E-07
COLORADO	1.55E-05	1.93E-06	3.44E-08	3.19E-08	1.15E-06	1.10E-06
CONNECTICUT	1.41E-05	1.90E-06	3.42E-08	3.18E-08	1.10E-06	1.06E-06
DELAWARE	1.41E-05	1.74E-06	2.72E-08	2.53E-08	1.05E-06	1.00E-06
FLORIDA	1.45E-05	1.92E-06	1.99E-08	1.86E-08	1.08E-06	1.03E-06
GEORGIA	1.42E-05	1.74E-06	2.31E-08	2.16E-08	1.07E-06	1.02E-06
HAWAII	1.49E-05	1.93E-06	1.97E-08	1.85E-08	1.08E-06	1.03E-06
IDAHO	1.51E-05	1.88E-06	3.24E-08	2.99E-08	1.09E-06	1.04E-06
ILLINOIS	1.48E-05	1.88E-06	3.18E-08	2.95E-08	1.16E-06	1.11E-06
INDIANA	1.55E-05	1.91E-06	3.03E-08	2.81E-08	1.13E-06	1.09E-06
IOWA	1.59E-05	1.96E-06	3.26E-08	3.03E-08	1.18E-06	1.13E-06
KANSAS	1.44E-05	1.86E-06	2.76E-08	2.56E-08	1.10E-06	1.05E-06
KENTUCKY	1.43E-05	1.81E-06	2.67E-08	2.48E-08	1.07E-06	1.02E-06
LOUISIANA	1.38E-05	1.78E-06	1.98E-08	1.85E-08	1.04E-06	9.95E-07
MAINE	1.64E-05	1.93E-06	3.65E-08	3.37E-08	1.15E-06	1.09E-06
MARYLAND	1.30E-05	1.79E-06	2.87E-08	2.67E-08	1.03E-06	9.89E-07
MASSACHUSETTS	1.48E-05	1.85E-06	3.50E-08	3.25E-08	1.10E-06	1.05E-06
MICHIGAN	1.60E-05	1.89E-06	3.46E-08	3.21E-08	1.20E-06	1.15E-06
MINNESOTA	1.68E-05	1.97E-06	3.87E-08	3.59E-08	1.22E-06	1.18E-06

MISSISSIPPI	1.33E-05	1.75E-06	2.07E-08	1.92E-08	1.04E-06	9.87E-07
MISSOURI	1.43E-05	1.83E-06	2.81E-08	2.61E-08	1.09E-06	1.05E-06
MONTANA	1.78E-05	1.89E-06	3.65E-08	3.39E-08	1.20E-06	1.14E-06
NEBRASKA	1.50E-05	1.95E-06	3.11E-08	2.89E-08	1.16E-06	1.11E-06
NEVADA	1.31E-05	1.88E-06	2.39E-08	2.23E-08	1.07E-06	1.02E-06
NEW HAMPSHIRE	1.59E-05	1.90E-06	3.57E-08	3.30E-08	1.14E-06	1.08E-06
NEW JERSEY	1.45E-05	1.86E-06	3.08E-08	2.87E-08	1.10E-06	1.05E-06
NEW MEXICO	1.42E-05	1.91E-06	2.70E-08	2.50E-08	1.06E-06	1.01E-06
NEW YORK	1.54E-05	1.88E-06	3.32E-08	3.09E-08	1.13E-06	1.08E-06
NORTH CAROLINA	1.55E-05	1.72E-06	2.42E-08	2.25E-08	1.06E-06	9.96E-07
NORTH DAKOTA	1.73E-05	2.04E-06	4.03E-08	3.76E-08	1.27E-06	1.22E-06
OHIO	1.64E-05	1.89E-06	3.18E-08	2.95E-08	1.15E-06	1.10E-06
OKLAHOMA	1.43E-05	1.80E-06	2.38E-08	2.22E-08	1.07E-06	1.02E-06
OREGON	1.61E-05	1.90E-06	3.07E-08	2.85E-08	1.11E-06	1.06E-06
PENNSYLVANIA	1.61E-05	1.85E-06	3.14E-08	2.91E-08	1.13E-06	1.08E-06
RHODE ISLAND	1.50E-05	1.85E-06	3.42E-08	3.18E-08	1.10E-06	1.06E-06
SOUTH CAROLINA	1.54E-05	1.73E-06	2.22E-08	2.08E-08	1.06E-06	9.97E-07
SOUTH DAKOTA	1.57E-05	2.01E-06	3.57E-08	3.29E-08	1.19E-06	1.15E-06
TENNESSEE	1.57E-05	1.82E-06	2.55E-08	2.38E-08	1.10E-06	1.04E-06
TEXAS	1.34E-05	1.78E-06	2.08E-08	1.94E-08	1.05E-06	1.00E-06
UTAH	1.55E-05	1.85E-06	3.16E-08	2.94E-08	1.12E-06	1.06E-06
VERMONT	1.67E-05	1.94E-06	3.76E-08	3.48E-08	1.18E-06	1.13E-06
VIRGINIA	1.50E-05	1.80E-06	2.76E-08	2.57E-08	1.09E-06	1.03E-06
WASHINGTON	1.68E-05	1.88E-06	3.35E-08	3.11E-08	1.15E-06	1.10E-06
WEST VIRGINIA	1.59E-05	1.90E-06	2.92E-08	2.71E-08	1.11E-06	1.06E-06
WISCONSIN	1.57E-05	1.92E-06	3.61E-08	3.35E-08	1.19E-06	1.14E-06
WYOMING	1.68E-05	1.98E-06	3.78E-08	3.53E-08	1.18E-06	1.13E-06

Developed by the EPA's Office of Transportation and Air Quality, MOVES can estimate total miles traveled and emissions from mobile sources like cars, trucks and motorcycles covering a wide range of pollutants at various levels (national, state etc.). The analysis includes GHGs (carbon dioxide (CO_2), CO_2 equivalents and methane (CH_4)) as well as other pollutants (carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), total organic compounds (TOG), and volatile organic compounds (VOC)). Combining these emission rates by type and state with the regression model predicted VMT, we can calculate the change in both GHG and pollutant emissions over various gas price scenarios.

4. Green Transportation Financing Policies

A common revenue-generation objective should be established first for the design and comparison of green transportation financing policies. The 2009 National Surface Transportation Infrastructure Financing Commission has recommended a 10 cents/gallon increase to the existing 18.4 cents/gallon federal gas tax. Though states would likely increase their own individual state gas taxes, to simplify our analysis we chose to measure the effects of only a federal tax increase. With the demand model developed in Section 3, we estimate that this 54.3 percent increase in tax rate would increase total tax revenue by 50.5 percent while decreasing total VMT by 2.5 percent. All three green transportation financing policies presented below are designed to produce the same amount of total revenue as a 28.4 cents/gallon federal gas tax. According to previous research, (*61*) a flat VMT fee of 1 cent/mile results is roughly revenue neutral to the present gas tax. Since the proposed polices are all variable distance-based user charges, we also fix the base (minimum) per-mile fee rate at 1 cent/mile for all policy scenarios. This section also demonstrates how demand models can be used to design transportation financing policies under a specific revenue goal.

4.1 Green VMT Fee

The first policy charges two different VMT fee rates based on vehicle fuel efficiency, which is directly related to fuel consumption and GHG emissions. 20 mpg (the mean fuel efficiency of today's passenger vehicle fleet) is set as the threshold value. If a vehicle has fuel efficiency greater than or equal to 20 mpg, the base VMT fee of 1 cent/mile will be assessed. The demand model is employed to compute the VMT fee rate that must be assessed on vehicles with

<20mpg fuel efficiency in order to achieve the same 50.5% revenue increase, which turns out to be 2.1 cents/mile.

4.2 Emission Tax

The second policy targets environmental externalities and considers pollution emissions and GHG emissions. Under this mileage-based emission tax, the base rate of 1 cent/mile is first charged on all users. A mark-up emission charge is then computed based on the vehicle emission ratings. The emission ratings are based on three factors: vintage, vehicle type (a proxy for engine size), and fuel efficiency (for GHG considerations). The final emission rating for a vehicle is the sum of the vintage, vehicle type, and fuel efficiency scores, and ranges from 0 to 15. Again, linear interpolation methods are used to determine the markup per mile fees for all vehicles. To generate the same revenue as the above policies, the highest markup fee rate should be 1.3 cents/mile, making the highest total VMT fee rate 2.3 cents/mile. For instance, a brand new Honda Civic will have a rating of 1 and be charged 1.08 cents/mile under this emission tax policy, and a ten-year old Ford F-150 will have a rating of 9, and be charged 1.78 cents/mile.

Emission Rating Scoring System

Vintage (age)	Score
>=30	6
25~29	5
20~24	4
15~19	3
10~14	2
5~9	1
<5	0

Vehicle Type	Score
Motorcycle	0
Car/station wagon	1
Passenger Van	2
SUV	2
Pickup truck	2
Other truck	3

Fuel Efficiency (MPG)	Score
< 10	6
10~14	5
15~19	4
20~24	3
25~29	2
30~34	1
>=35	0

4.3 Congestion Pricing

The third policy represents a nation-wide congestion pricing scheme. It charges road users living in areas with no or minimum congestion the base VMT fee rate of 1 cent/mile. Road users living in areas with higher levels of congestion will be charged per mile taxes that result in higher VMT fees. Congestion in urbanized areas is measured by the travel time indices (TTI) from the Texas Transportation Institute Urban Mobility Report. (*62*) Without more specific local and corridor data, we assumed away the variance in corridor-level congestion within each metropolitan statistical area. Congestion in rural areas is assumed to be nonexistent, and therefore the base VMT fee rate applies to all rural areas. The TTIs measure the ratios of travel time during the peak period to free-flow travel time in all urbanized areas in the U.S. and range from 1 to 1.83 with 1.83 representing the highest level of congestion. The VMT fee rates in urban areas are positively correlated with their travel time indices. Linear interpolation methods are adopted, which implies that an area with a Travel Time Index of 1.415 (halfway between 1 and 1.83) will incur a VMT fee rate halfway between the base rate and the highest rate. Based on demand model outputs, it is computed that the highest VMT fee rate needs to be 3.4 cents/mile for this congestion pricing policy to generate the same revenue as the 28.4 cents/gallon federal gas tax. In other words, those living in the most congested city, Los Angeles (highest travel time index = 1.83) area will be charged 3.4 cents/mile under this policy, which is about three times of what drivers in Los Angeles pay for driving right now. Those living in San Francisco, Washington DC, Chicago, Houston, Boston, and other congested urban areas will be charged VMT fee rates slightly lower than 3.4 cents/mile because the most congested cities will be penalized the most under a nation-wide congestion pricing scheme.

5. Measures of Policy Effectiveness

In order to evaluate the effectiveness of the proposed green transportation financing policies with the VMT demand model, a number of performance measures are developed in this section and presented below.

Notation

M	Annual Household Miles Driven
P	Per Mile Tax/Fee rate
AFE	Average Household Fuel Efficiency
G	State Gas Tax per gallon
HTF	Highway Trust Fund collected from proposed green transportation financing policies
Green	Subscript indicating values under proposed green transportation financing policies
Current	Subscript indicating values under current 18.4 cents/gallon federal gas tax
H	Index of all household in our sample
S	Index of States in the U.S.

Performance Measures

Total Federal Revenue	$\Sigma_H[P*M_{Green}]/.00015$, 0.00015 is the ratio of total households in our sample to total households in the U.S..
State Gas Tax Revenue	$\Sigma_S\ [M_{S,Green}*G/(AFE)]/$% of households from state S represented in our sample
HTF Reimbursement	Total Federal Revenue Collected from State S * HTF Repayment Ratio based on Existing Funding Formula
Total State Revenue	State Gas Tax Revenue + HTF Reimbursement
VMT Reduction by Household	$(M_{Green} - M_{Current})/M_{Current}$
VMT Reduction by Group	$(\Sigma_H M_{Green} - \Sigma_H M_{Current})/\Sigma_H M_{Current}$ for each population group
Gasoline Consumption	M/AFE
Federal Taxes Paid by Household	$(M_{Green})*(P)$

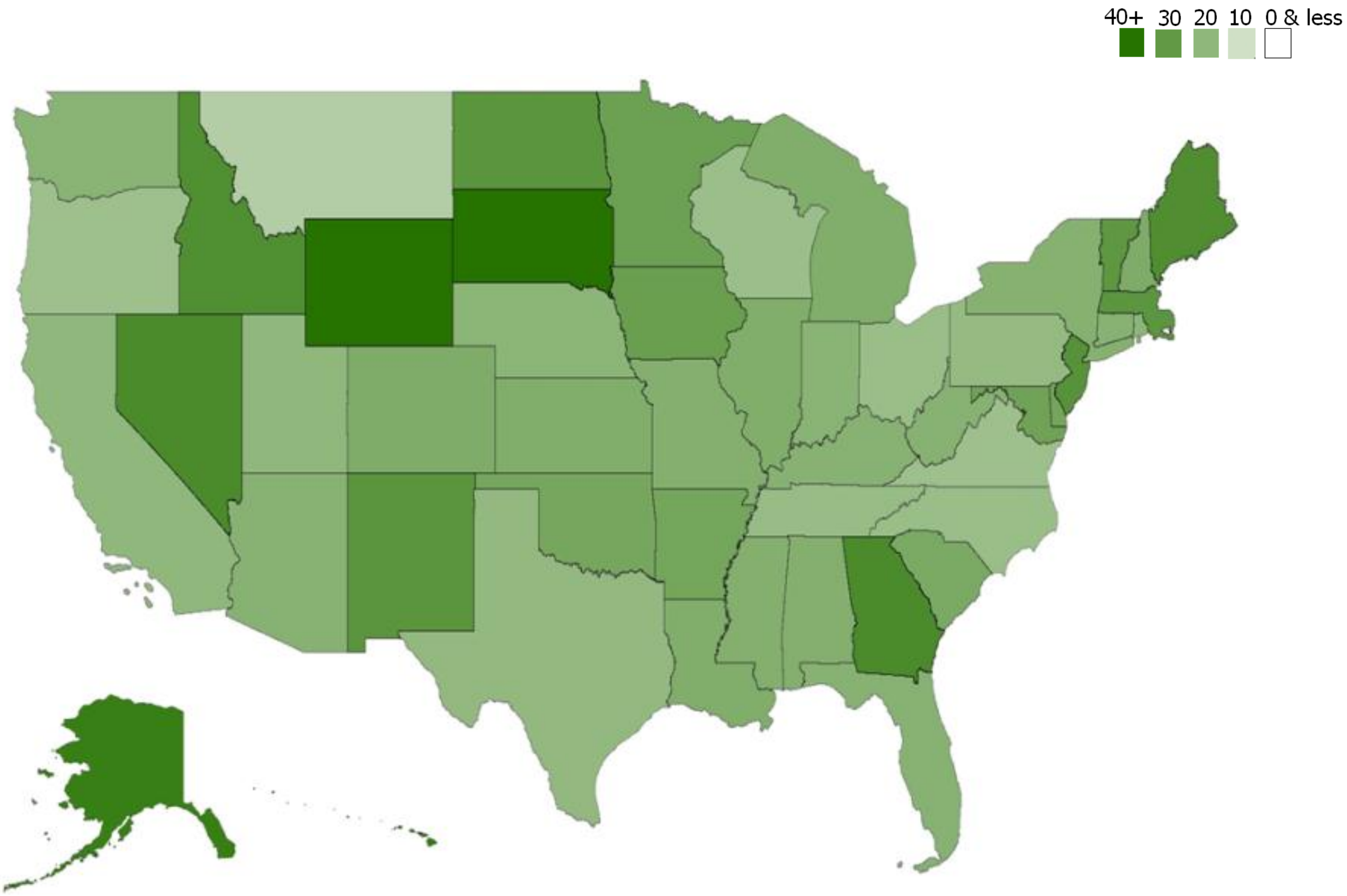
Total Taxes Paid by Household	$(M_{Green})*(P + G_{state}/AFE)$
Change in Consumer Surplus	$0.5(M_{Green}+M_{Current})(P_{Current} - P_{Green})$, Rule-of-Half Method
Change in Welfare	Change in Consumer Surplus + Taxes Paid

6. Results

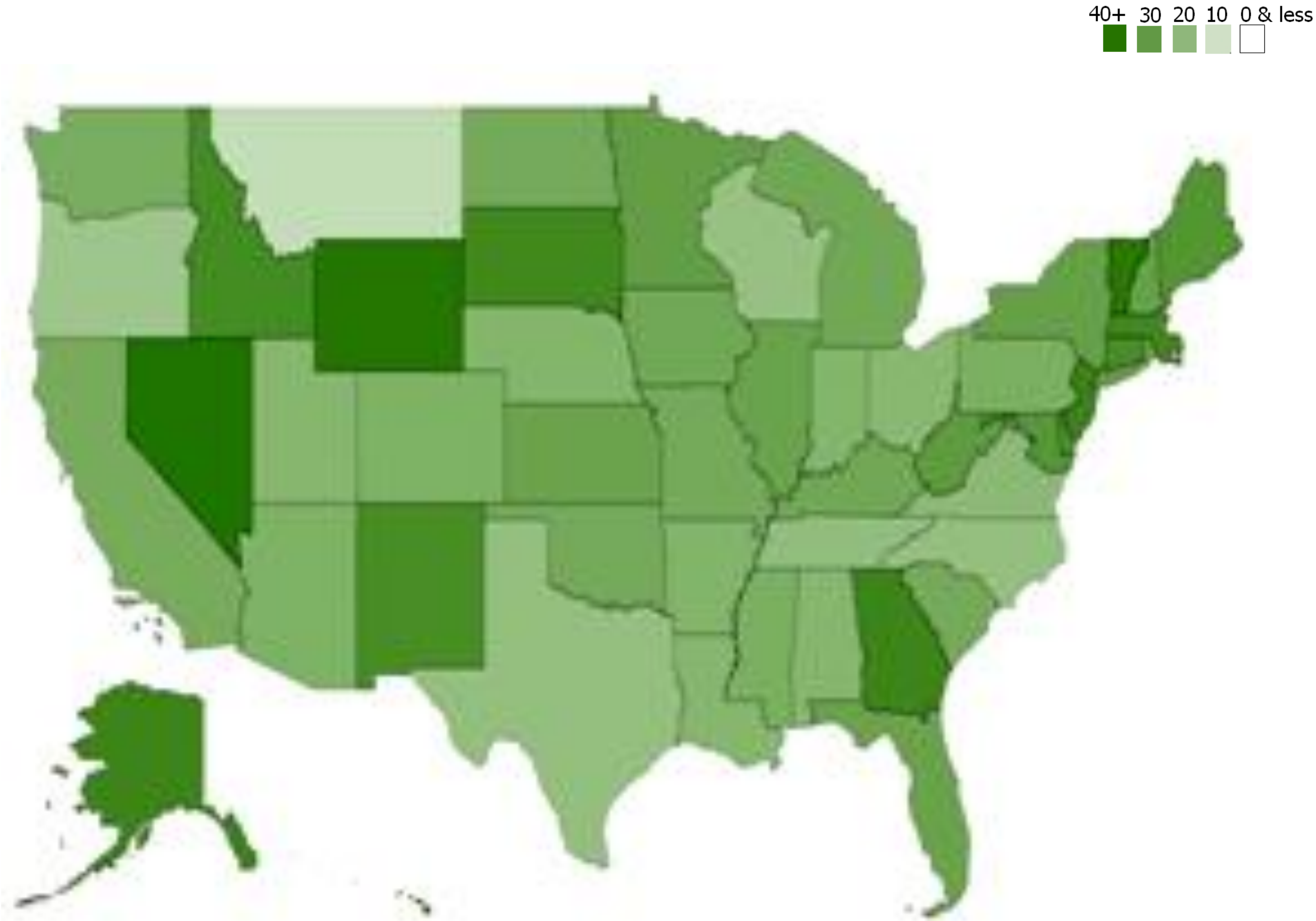
6.1. Impact on Federal and State Transportation Revenues

By design, all three green financing policies will generate the same amount of total federal revenue that is 50.5% higher than what is generated by the current 18.4 cents/gallon federal gas tax. This is a sizable increase of revenue for the Highway Trust Fund (HTF). With the reallocation of the HTF to individual states based on current funding formulas, (*63*) states should benefit from the proposed green financing policies with increased payment from the federal HTF even if the state tax remains constant. The funds are apportioned with a complex arithmetic tool by the Federal Highway Administration to states in 13 funding categories including the National Highway System and Interstate Maintenance. The increase of federal transportation taxes paid also implies a reduction in VMT, which reduces state gas tax revenues (assuming state gas tax rates do not change). The actual impact of the proposed green policies on total transportation revenue for a particular state also depends on the donor/donee status of the state, and the nature of the green financing policy. After all these factors are considered, the percentage change in total transportation revenue for each state is computed and illustrated in Figures 4 a~c for all three proposed policy scenarios. In general, the green VMT fee and the emission tax have similar effects on state revenues, because both policies attempt to internalize environmental externalities with slightly different methods. Though all states experience revenue gains under these two policies, rural states like Alaska, Nevada, South Dakota, and Wyoming benefit the most because they tend to have vehicle fleets with high percentages of fuel-inefficient, older, and larger vehicles. This is because households in these states will pay much higher per-mile taxes, which results in higher tax revenue contributions to the federal HTF and consequently higher state reimbursements after HTF reallocation. For the same reason, states with large congested cities including California, Illinois, Maryland, New Jersey, and Massachusetts have the most revenue to gain with congestion pricing, while rural states such as those in the upper Midwest experience shortfalls in revenue as shown by the light colored states in Figure 4c.

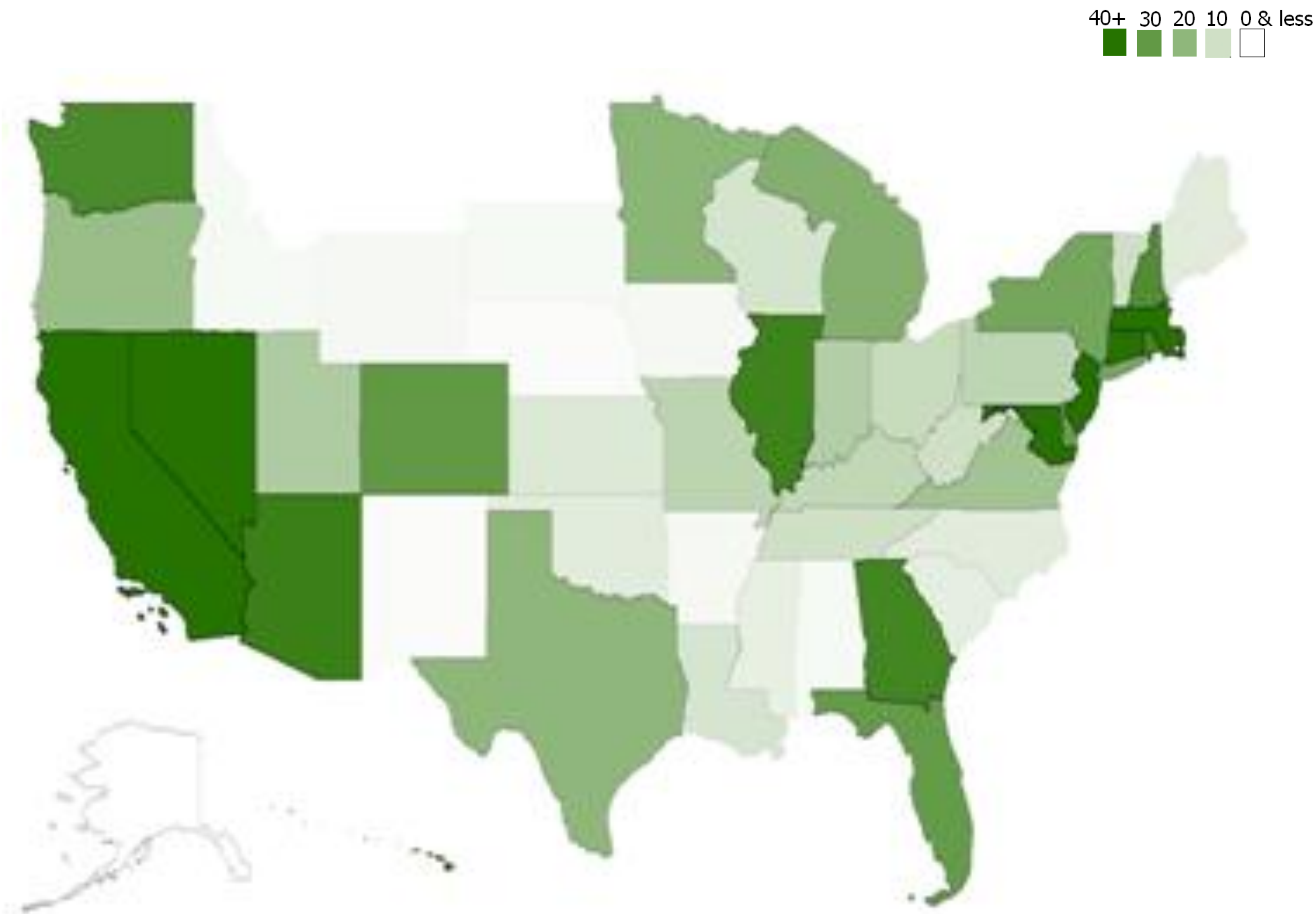
Figure 4. Percent Change in State Transportation Revenue from Green Financing Policies



a.Green VMT Fee



b. **Emission Tax**

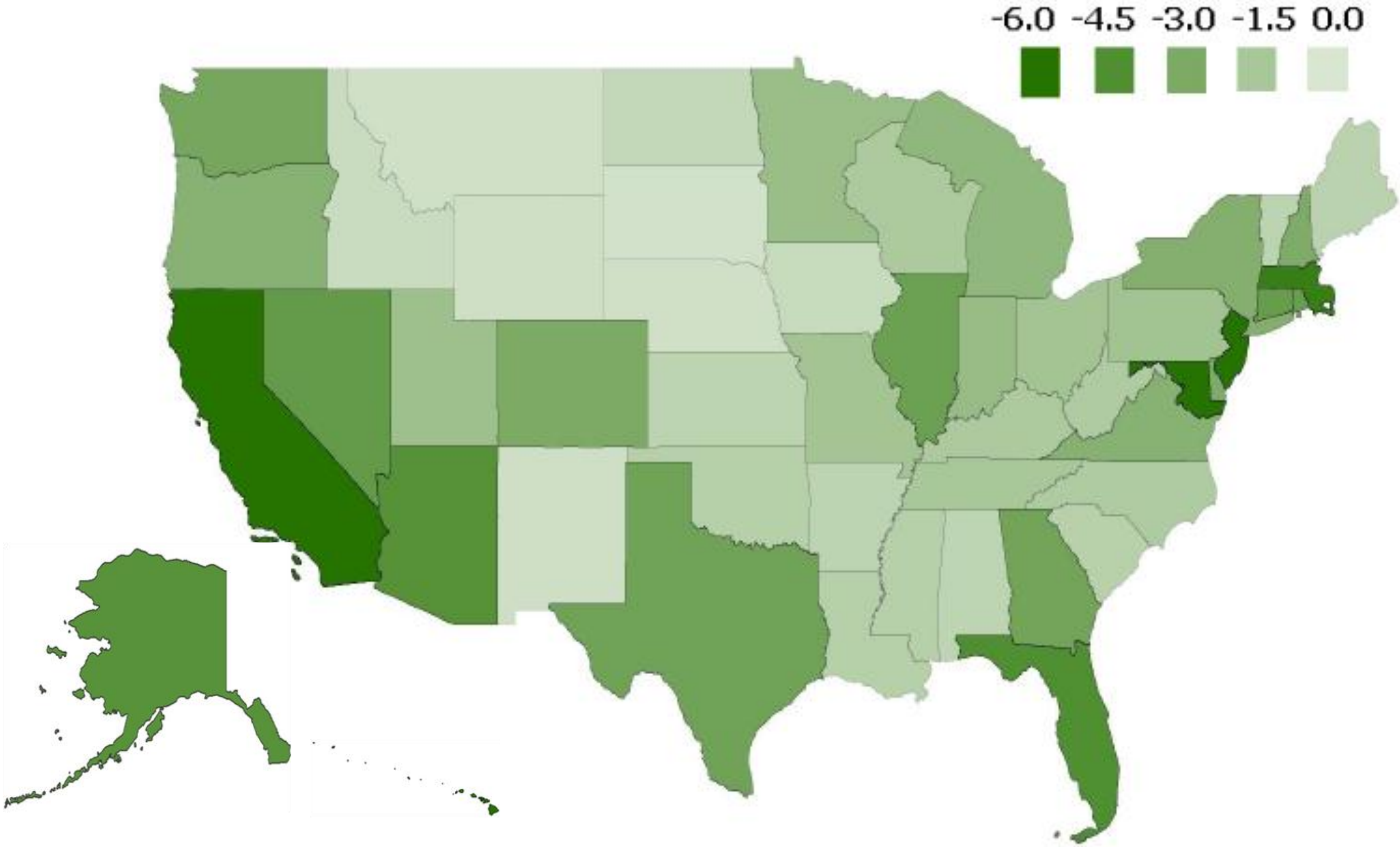


c. **Congestion Pricing**

6.2. Impact on Vehicle Miles Traveled

Since all three proposed policies impose a higher cost of driving to almost all households, VMT is expected to decrease accordingly. For the average household, the per-mile cost of driving increases by approximately 12%. Results show that the total national VMT decreases by 2.57% under the green VMT fee, 2.76% under congestion pricing, and 2.93% under emission tax. The actual percentage reductions in fuel consumption and emissions are both larger since these policies penalize the use of fuel-inefficient vehicles and driving in congested conditions. We will estimate the actual sustainability impact with fuel consumption and emission models in our future research. The nation-wide congestion pricing scheme has quite different VMT impact in different states (see Figure 5). In states with the highest levels of congestion including California, Maryland, Massachusetts, and New Jersey, VMT decreases by more than 6%. It is important to note that once the federal fuel tax were to switch to a distance based mechanism, states would likely switch to distance based state gas taxes in the ensuing 5-7 years. Based on previous research that compares the gas tax to a flat VMT fee, we can conclude that a complete switch to distance based fees at both the state and federal levels would likely result in even further declines in vehicle miles traveled. A revenue neutral switch to a flat federal VMT fee at the present revenue level resulted in some rural regions actually showing an increase in miles traveled. The distribution of change across different states showed an average overall decrease in miles traveled. When the federal tax was raised, all states showed a decrease in miles traveled. Households with low efficiency vehicles would find driving more inexpensive with a VMT fee and would likely be the households least affected by a change to a distance based user fee that was not linked to vehicle fuel efficiency or congestion levels.

Figure 5. Percent Change in VMT by State under Nation-Wide Congestion Pricing



6.3. Distributional Impact by Income, Geographical Location, Ethnicity, and Age Groups

Results on distributional effects of the green transportation financing policies are presented both numerically and graphically. While some readers may find the numerical results in the tables a bit overwhelming, they are intended to provide additional details and supplement the summary results in the figures.

Under all policy scenarios, household total VMT decreases with low-income households showing the largest percent reduction as shown in Figure 6a and Tables 5a~c.

Table 5. Household Changes in Welfare ($) and Percent Change in VMT from Green Financing Policies by Income

a. Green VMT Fee

Income Group	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent change in VMT
>/=$0,<$10K	$ (42.03)	$ 31.68	$ (10.35)	-9.23%
>/=$10K,<$20K	$ (57.62)	$ 48.24	$ (9.38)	-6.18%
>/=$20K,<$30K	$ (77.01)	$ 67.57	$ (9.44)	-4.76%
>/=$30K,<$40K	$ (94.23)	$ 85.46	$ (8.76)	-3.59%
>/=$40K,<$50K	$(113.87)	$ 105.87	$ (8.00)	-2.73%
>/=$50K,<$60K	$(125.68)	$ 119.58	$ (6.10)	-1.92%
>/=$60K,<$70K	$(129.89)	$ 124.99	$ (4.90)	-1.45%
>/=$70K,<$80K	$(140.73)	$ 137.31	$ (3.42)	-0.93%
>=$80K	$(150.84)	$ 149.83	$ (1.02)	-0.30%

b. Congestion Pricing

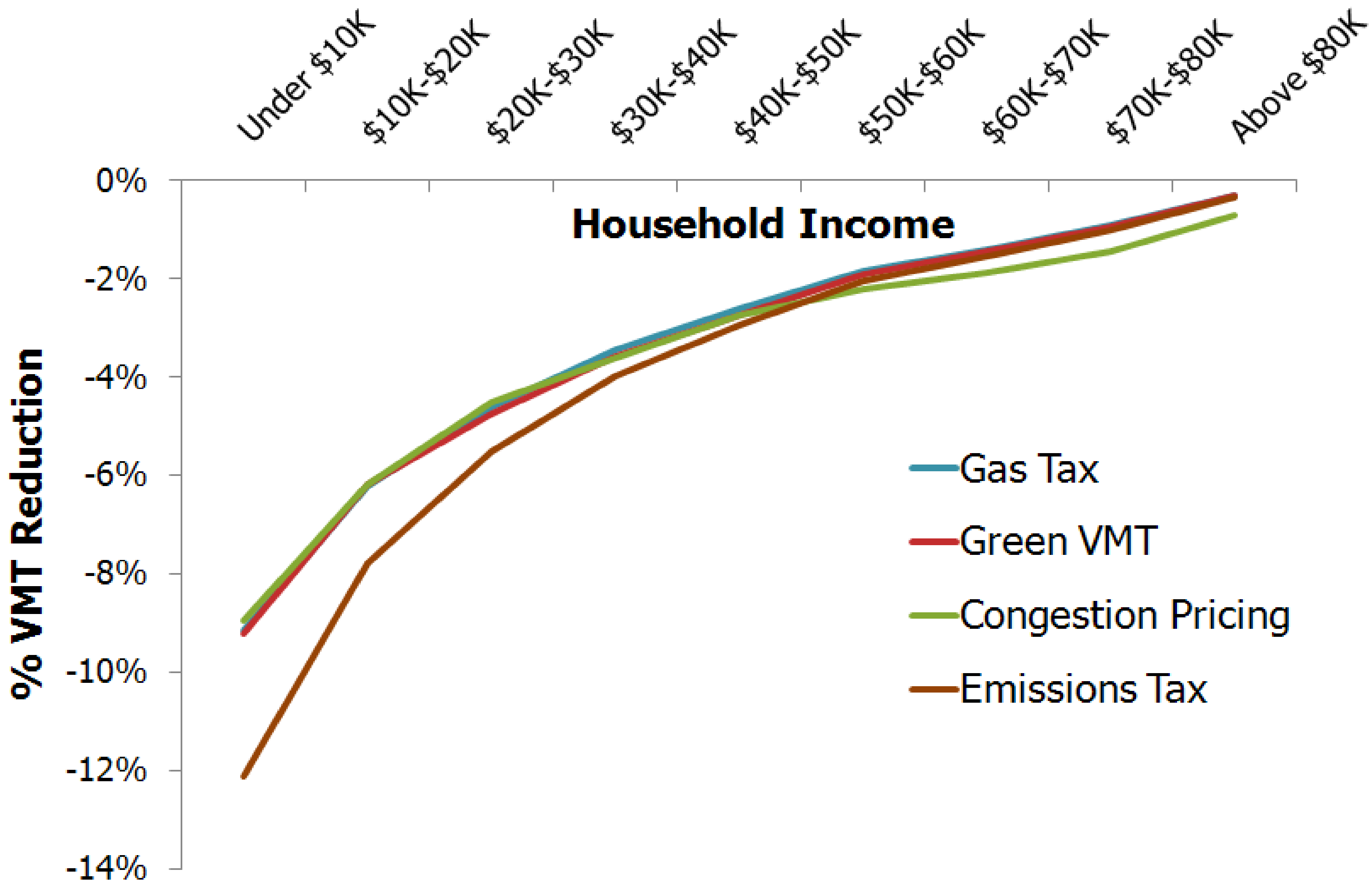
Income Group	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent Change in VMT
>/=$0,<$10K	$ (35.26)	$ 24.67	$ (10.60)	-8.94%
>/=$10K,<$20K	$ (49.44)	$ 39.35	$ (10.09)	-6.19%
>/=$20K,<$30K	$ (61.01)	$ 51.59	$ (9.42)	-4.52%
>/=$30K,<$40K	$ (80.09)	$ 70.48	$ (9.60)	-3.63%
>/=$40K,<$50K	$ (96.92)	$ 88.33	$ (8.58)	-2.75%
>/=$50K,<$60K	$(120.02)	$ 112.36	$ (7.66)	-2.22%
>/=$60K,<$70K	$(146.65)	$ 139.52	$ (7.13)	-1.88%
>/=$70K,<$80K	$(178.58)	$ 172.63	$ (5.94)	-1.43%
>=$80K	$(201.36)	$ 198.20	$ (3.16)	-0.71%

c. Emission Tax

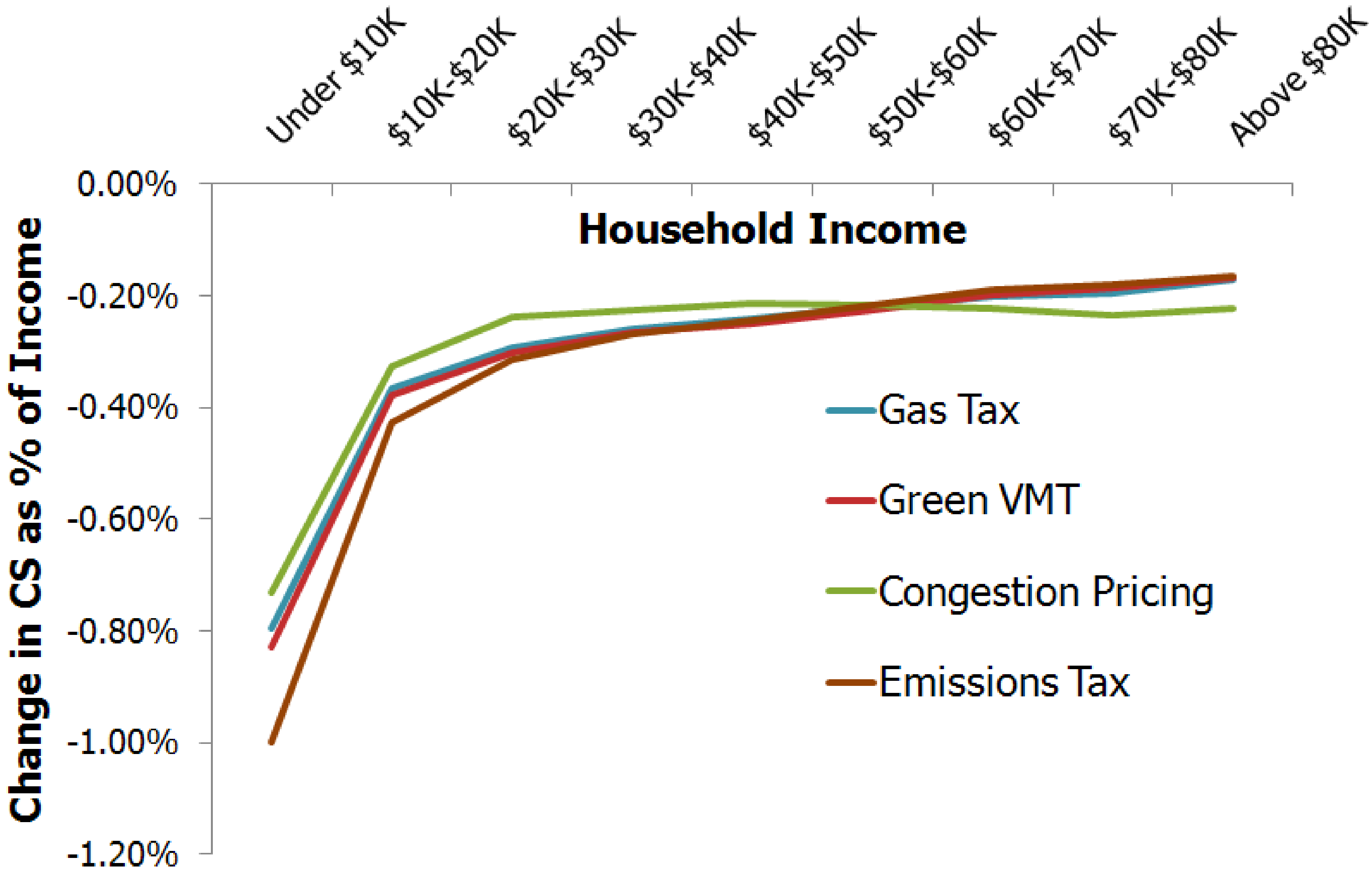
Income Group	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent Change in VMT
>/=$0,<$10K	$ (50.63)	$ 38.39	$ (12.24)	-12.11%
>/=$10K,<$20K	$ (65.00)	$ 54.60	$ (10.41)	-7.78%
>/=$20K,<$30K	$ (79.59)	$ 70.14	$ (9.44)	-5.53%
>/=$30K,<$40K	$ (95.00)	$ 86.77	$ (8.23)	-3.97%
>/=$40K,<$50K	$(110.78)	$ 103.58	$ (7.20)	-2.93%
>/=$50K,<$60K	$(119.58)	$ 114.12	$ (5.46)	-2.06%
>/=$60K,<$70K	$(124.05)	$ 119.71	$ (4.33)	-1.54%
>/=$70K,<$80K	$(135.03)	$ 131.89	$ (3.14)	-1.02%
>=$80K	$(149.22)	$ 148.25	$ (0.97)	-0.34%

Low income households have a greater sensitivity to price increases, and any increase in tax payments would represent a greater percentage of their income. The tax increases analyzed in this thesis are not a great enough price signal however to significantly affect the driving decisions of high income households. The model also shows that lower income groups experience the greatest reduction in consumer surplus under the emission tax scheme (Figure 6b). This is likely due to the fact that lower income households are less likely to own newer, more fuel efficient vehicles and so will be taxed at higher VMT fee rates under the Green VMT and Emission Tax policies. Affluent households tend to be charged less under fees linked to vehicle fuel efficiency and emissions because they can more easily afford newer vehicles. Our data shows that about 30 percent of the lowest income group own vehicles with average fuel efficiencies less than or equal to 18 miles per gallon while only about 24 percent of the highest income group fall into this category. Based on the consumer surplus findings, all three green financing policies are equitable for households with more than $25,000 annual income. The overall impact on these households (converted to a monetary value and measured as a percentage

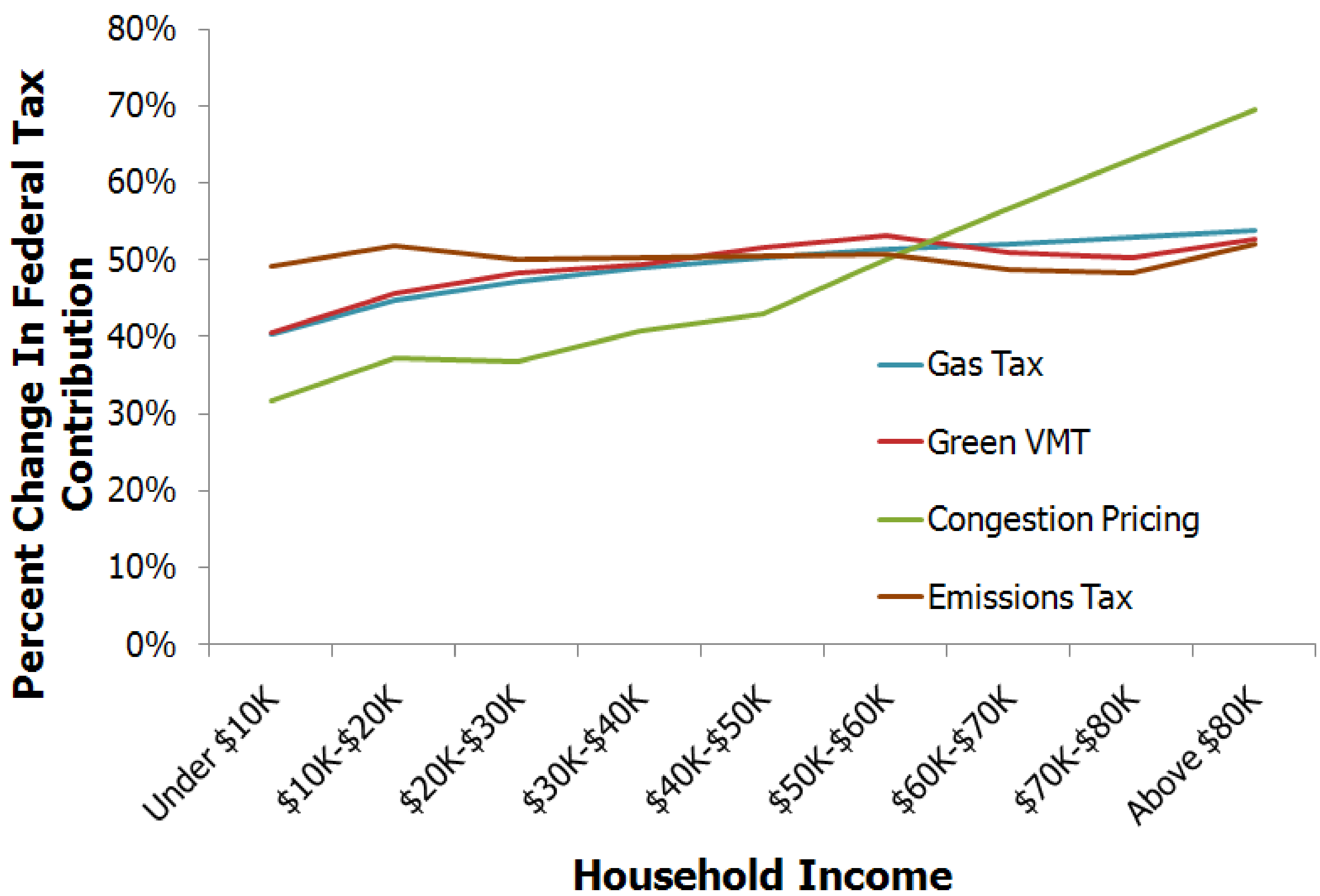
Figure 6. Distributional Effects of Green Financing Policies by Income Groups



a. **Household Percent VMT Reduction**



b. Household Change in Consumer Surplus as a Percentage of Income



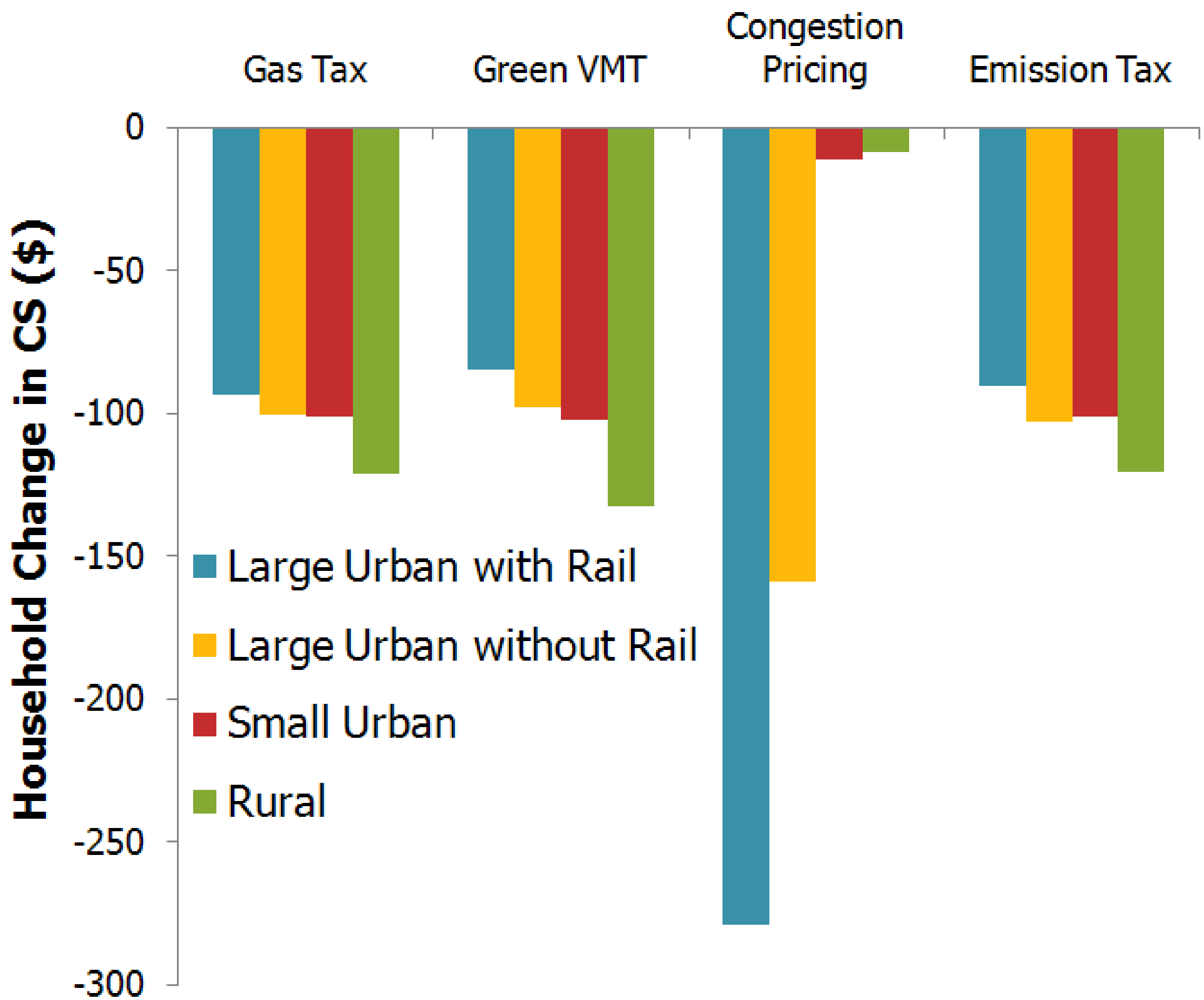
c. Household Percent Change in Federal Tax Contribution

income in Figure 6b) is about the same. The households making less than $25,000 a year need to be compensated, possibly in the form of a transportation tax credit.

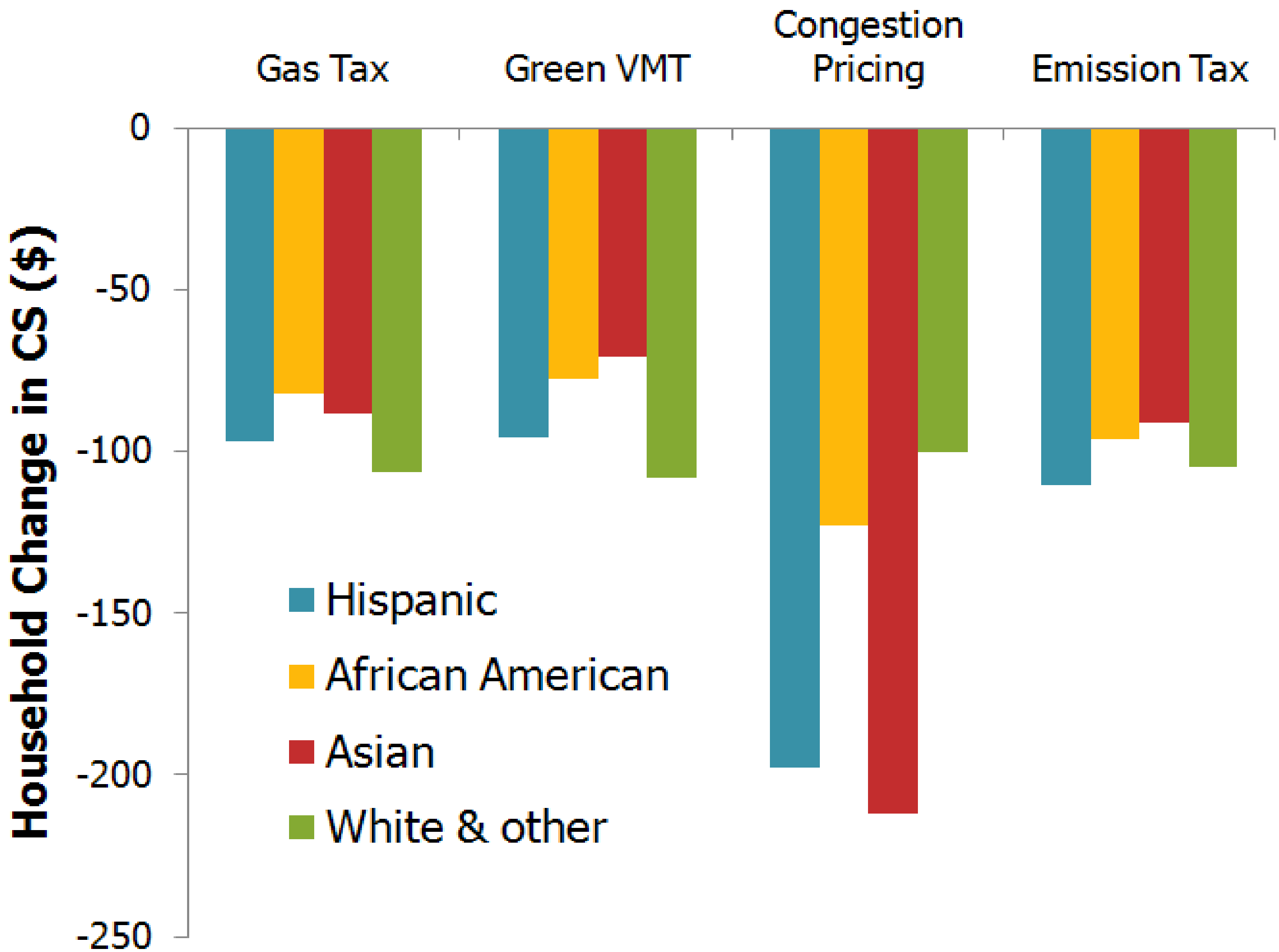
It is interesting to observe that the congestion pricing policy, when implemented at the national level, is the least regressive of all policies analyzed including the existing gas tax. This is because households in congested urban areas tend to earn more income than those living in uncongested areas. Another key factor is that in urban areas there tends to be more public transit alternatives and the urban poor disproportionately tend to use public transit. The regional analysis in this thesis focuses on the average household in each region and therefore does not consider distributional effects among households within the same Census region. We further analyze the distributional impact by income group. Under congestion pricing, higher-income households also pay significantly more federal transportation taxes as a percentage of income compared to what they are paying now (Figure 6c). The percent increase in federal tax contribution is similar across most income groups for the emission tax and the green VMT fee with low income groups again being most negatively affected by the emission tax.

Based on transportation taxes paid, rural households unsurprisingly benefit more from the congestion pricing scheme than urban households. It should be noted that urban households paying higher congestion-based VMT fees should also benefit from reduced levels of congestion, which is not considered in our analysis. In contrast, the emission tax and the green VMT fee both cause a greater reduction in consumer surplus for rural households (Figure 7a, Tables 6a~c), because rural households own higher shares of older, larger, and fuel inefficient vehicles. Our data shows that 31.3 percent of rural households own vehicles with fuel efficiencies of 18 miles per gallon or less while only 21.6 percent of MSA 1 households fall into this category. Another possible explanation for decreased consumer surplus could be that rural drivers have a greater

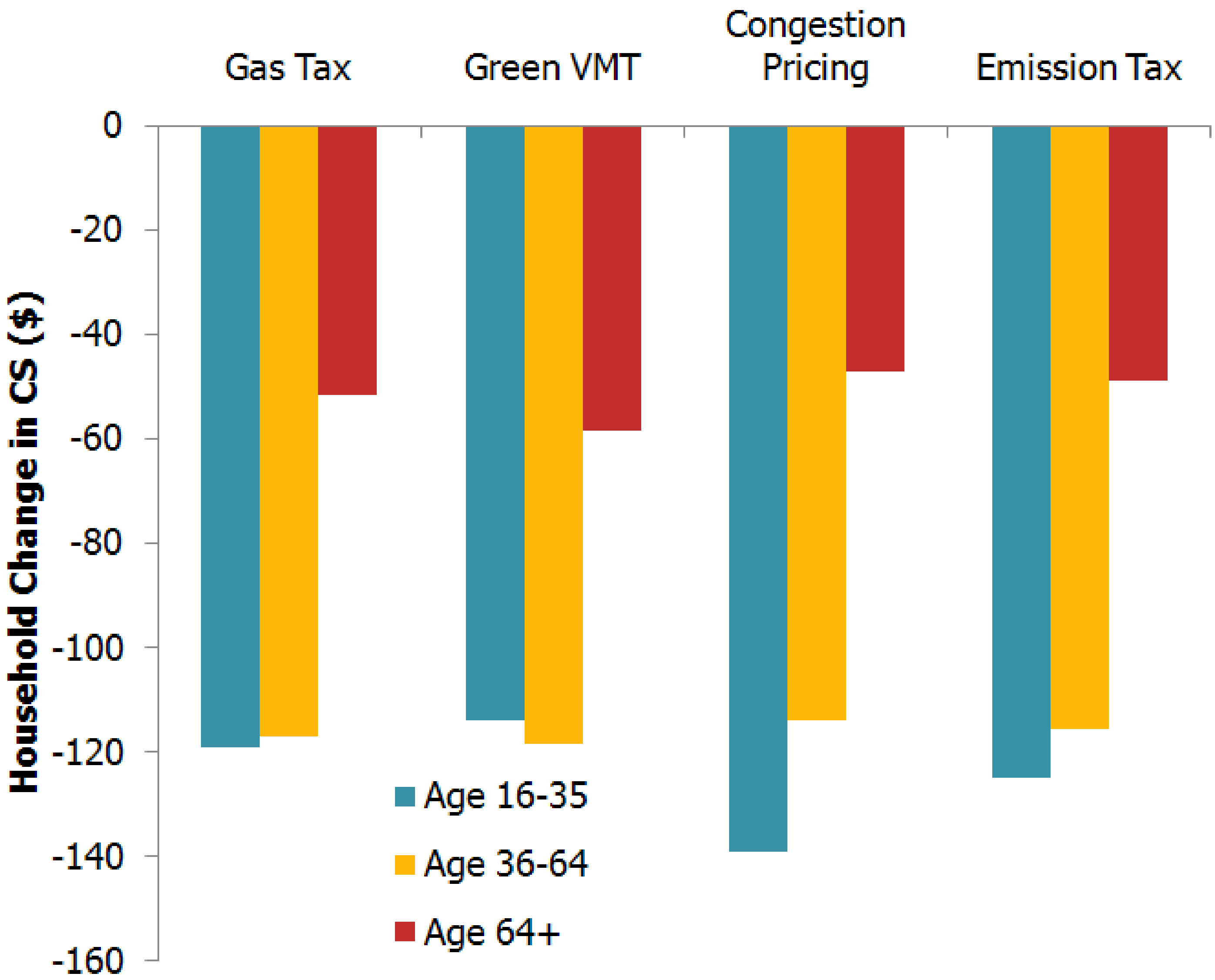
Figure 7. Household Change in Consumer Surplus ($) by Level of Urbanization, Ethnicity, and Age Group



a. Level of Urbanization



b. Ethnicity Group


Gas Tax
Green VMT
Congestion Pricing
Emission Tax
0
-20
-40
-60
-80
-100
-120
-140
-160
Household Change in CS ($)
Age 16-35
Age 36-64
Age 64+

c. **Age Group**

Table 6. Household Changes in Welfare ($) and Percent Changes in VMT from Green Financing Policies by Socio-Demographic Groups

a. Green VMT Fee

	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent Change in VMT
MSACAT1	$ (84.57)	$ 79.31	$ (5.26)	-2.29%
MSACAT2	$ (98.12)	$ 92.19	$ (5.94)	-2.32%
MSACAT3	$(102.36)	$ 95.33	$ (7.03)	-2.66%
Rural	$(132.48)	$ 123.12	$ (9.36)	-2.91%
Hispanic	$ (95.73)	$ 86.59	$ (9.14)	-3.58%
African American	$ (77.51)	$ 71.01	$ (6.51)	-3.01%
Asian	$ (70.68)	$ 65.95	$ (4.73)	-2.39%
Other	$(107.97)	$ 101.02	$ (6.95)	-2.51%
Age Group 16-35	$(113.79)	$ 105.83	$ (7.96)	-2.69%
Age Group 36-64	$(118.37)	$ 111.56	$ (6.81)	-2.23%
64+	$ (58.50)	$ 52.35	$ (6.15)	-4.34%

b. Congestion Pricing

	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent Change in VMT
MSACAT1	$(278.85)	$ 256.49	$ (22.36)	-7.12%
MSACAT2	$(159.08)	$ 148.03	$ (11.05)	-4.10%
MSACAT3	$ (11.29)	$ 10.31	$ (0.98)	-0.69%
Rural	$ (8.55)	$ 7.75	$ (0.80)	-0.53%
Hispanic	$(198.02)	$ 174.80	$ (23.22)	-6.94%
African American	$(123.16)	$ 111.47	$ (11.68)	-4.73%
Asian	$(211.67)	$ 193.63	$ (18.04)	-6.26%
Other	$(100.20)	$ 93.05	$ (7.15)	-2.45%
Age Group 16-35	$(138.88)	$ 126.67	$ (12.21)	-3.58%
Age Group 36-64	$(113.85)	$ 106.51	$ (7.34)	-2.26%
64+	$ (46.98)	$ 41.74	$ (5.24)	-3.56%

c. Emission Tax

	Average Change in CS	Change in state revenue attributed by each population subgroup	Change in Aggregate Welfare associated with each subgroup	Percent Change in VMT
MSACAT1	$ (90.64)	$84.89	$ (5.75)	-2.85%
MSACAT2	$(103.18)	$96.98	$ (6.21)	-2.79%
MSACAT3	$(101.30)	$94.50	$ (6.80)	-3.02%
Rural	$(120.22)	$111.96	$ (8.26)	-3.05%
Hispanic	$(110.49)	$100.06	$(10.44)	-4.61%
African American	$ (96.48)	$88.33	$ (8.15)	-4.17%
Asian	$ (91.36)	$84.55	$ (6.81)	-3.55%
Other	$(105.06)	$98.48	$ (6.57)	-2.80%
Age Group 16-35	$(125.00)	$115.72	$ (9.28)	-3.51%
Age Group 36-64	$(115.75)	$109.31	$ (6.44)	-2.48%
64+	$ (49.00)	$44.21	$ (4.79)	-4.10%

tendency to drive at very high speeds due to the very low traffic flows and so burn gas more inefficiently, though this effect cannot be captured by our model. The Green VMT fee and the Emissions Tax affect the West South Central and East South Central regions of the U.S. most negatively. The Pacific and New England regions show the lowest reduction in aggregate welfare associated with each subgroup under these environmentally friendly policies. More affluent regions are not as price sensitive to changes in revenue policies, tend to drive more (i.e. generate more federal revenue) and also tend to have better developed transit options. Congestion pricing has a somewhat opposite effect reducing the aggregate welfare associated with each subgroup, most drastically for the Pacific and New England regions. The West North Central and East South Central regions see the lowest change in aggregate welfare associated with each subgroup.

Our analysis of distributional effects by ethnic groups (Figure 7b, Tables 6a-c) indicates that Asians and Hispanics are more negatively affected by congestion pricing possibly because higher percentages of these two ethnic groups reside in large congested urban areas. According to our data about 39 percent of Hispanics and 46 percent of Asians live in large urban areas with rail while 7 and 13 percent respectively live in rural regions. The green VMT fee and emission tax most negatively affect Hispanics and Whites, but not to a significant degree. Figure 7c shows the impacts by age group. All policies seem to impact the younger population groups more than the 64+ group. The elderly population drives much less and thus impacted less by increases in per-mile driving costs.

6.4 Impacts on Emissions and Vehicle Ownership Choices with Increased Gas Prices

By using the coefficients from the discrete choice models, the highest probability vehicle bundle was determined for each household at each gas price scenario. The average fuel efficiency for each bundle was entered into the regression model and the total VMT was calculated for each scenario. By combining the VMT with the MOVES emission rates, the analysis shows that with lowered VMT, both vehicle emissions of pollutants and greenhouse gases decline as gas prices rise. Emissions drop up to about 30 percent at the highest gas price scenario- a 300% increase. VMT drops to about 40% less compared to the current scenario. Figure 8 and Table 7 show the decline in both emissions and VMT. Figure 9 shows the increase in fuel efficiency as gas prices rise. Households on average choose to purchase vehicles with higher fuel efficiencies. The vehicle fuel efficiencies rise from an average of 18.4 miles per gallon to 19.03 miles per gallon, an average increase of up to 3.43 percent.

Figure 8. Percent Change in Emissions and VMT with Respect to Various Gas Price Scenarios

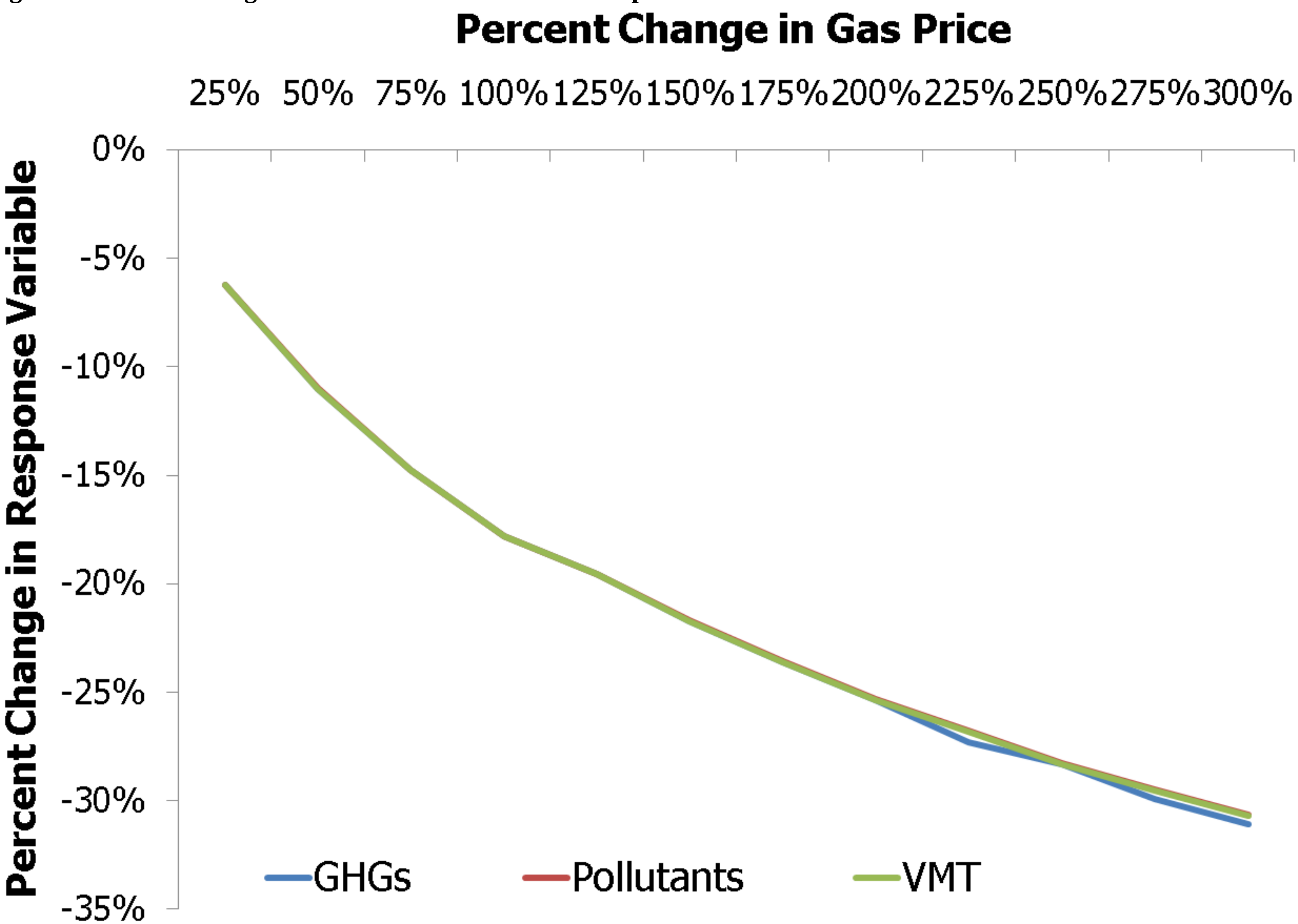


Figure 9. Percent Change in Average Fuel Efficiency at Various Price Scenarios Relative to Current Prices

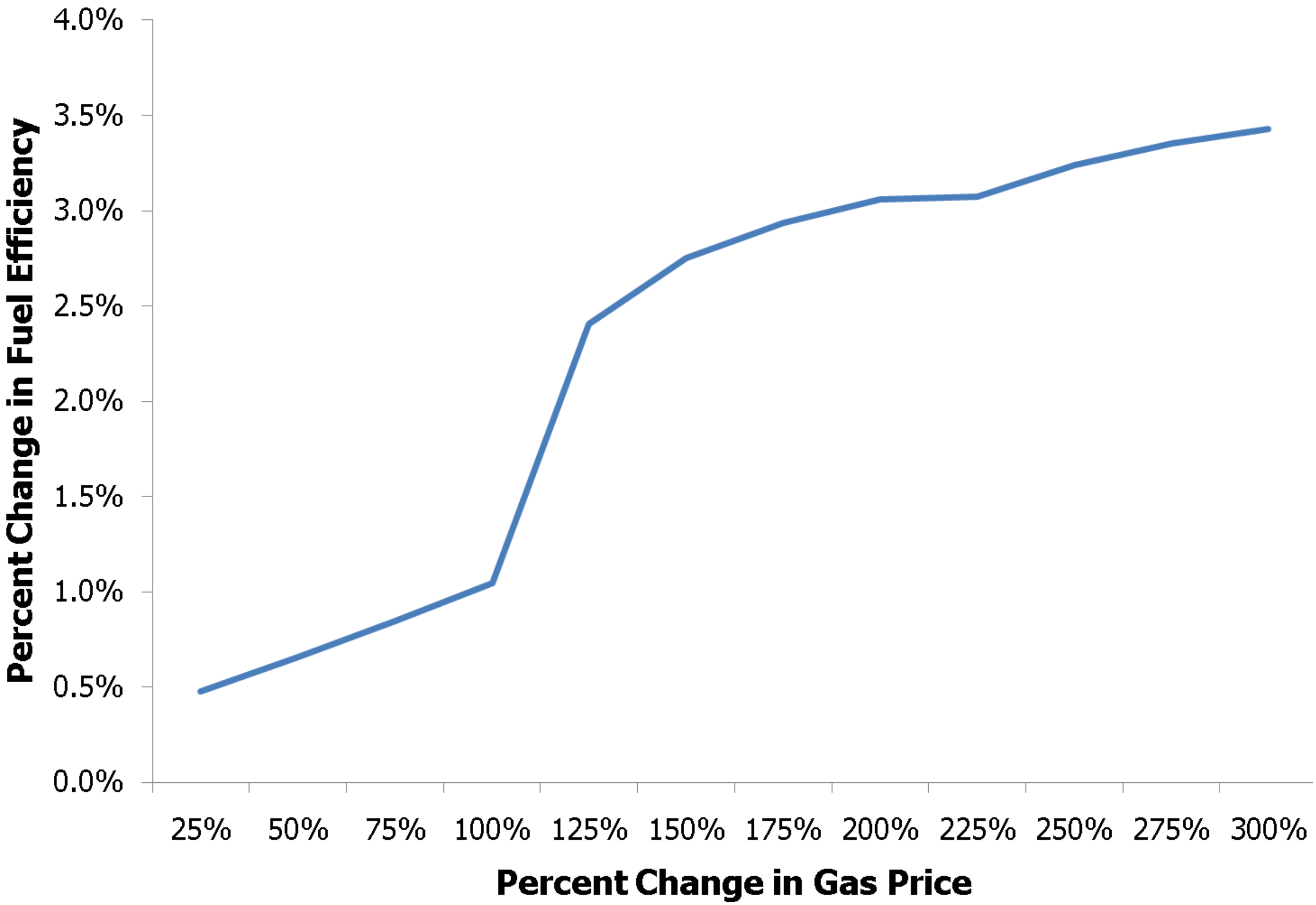


Table 7. Percent Change in Emissions, VMT and Fuel Efficiency at Various Gas Price Scenarios

Price Change	25%	50%	75%	100%	125%	150%
GHG	-6.22%	-11.01%	-14.78%	-17.82%	-19.57%	-21.72%
Pollutants	-6.22%	-11.00%	-14.77%	-17.81%	-19.54%	-21.68%
VMT	-6.65%	-11.86%	-16.09%	-19.62%	-22.63%	-25.23%
FE	0.48%	0.66%	0.85%	1.04%	2.40%	2.75%
Price Change	**175%**	**200%**	**225%**	**250%**	**275%**	**300%**
GHG	-23.63%	-25.37%	-27.28%	-28.75%	-29.90%	-31.10%
Pollutants	-23.59%	-25.33%	-26.78%	-28.32%	-29.48%	-30.66%
VMT	-27.51%	-29.53%	-31.35%	-32.98%	-39.94%	-41.23%
FE	2.94%	3.06%	3.07%	2.81%	3.35%	3.43%

7. Conclusion

Recent debates and studies in the U.S. on distance-based use charge and vehicle mileage fees are largely driven by interests in a more sustainable funding stream for financing the surface transportation system. (*64,65*) Pilot tests on VMT fee technology and implementation have also been recently conducted at the state and national levels. (*66,67*) Many researchers and practitioners have also recognized and promoted the possibility of internalizing the congestion and environmental externalities of driving with variable VMT fees. (*68*) This thesis builds on this recognition, develops theoretically sound and practically feasible green transportation financing policies based on the variable VMT fee concept, and analyzes the impact of the proposed policies on revenue, VMT, sustainability, and equity at the national and state levels. The policies designed and evaluated include a green VMT fee linked to fuel efficiency, an emission tax targeting pollution and GHG emissions, and a nation-wide congestion pricing scheme.

Reasonable variable VMT fee structures can be designed to achieve pre-determined revenue goals, such as those proposed by recent Congressional Commissions on transportation financing. With the same base rate of 1 cent per mile, the highest VMT fee rates, under the three green transportation financing policies, are 2.1, 3.4, and 2.3 cents per mile respectively, which are significantly lower than per mile charges on existing congestion pricing facilities. Green transportation financing policies can have quite different impacts on state transportation revenues, which are practical issues that need to be addressed with either changes in the HTF reallocation formulas or other revenue redistribution mechanisms. The VMT reduction effects of the proposed green transportation financing polices are moderate on average (about 2~3% reduction), though the reduction in fuel consumption and vehicle emission should be significantly larger. More aggressive policies that impose higher penalties on congestion and environmental externalities can produce even more significant benefits.

Overall, the distributional impact of green transportation financing policies is similar to that of the existing gas tax. (*69*) Households with income higher than $25,000/year are about equally affected by these policies. Households with income lower than $25,000/year are hurt more and should be compensated. Policies internalizing congestion externalities tend to hurt urban residents more, while policies internalizing environmental externalities tend to hurt rural residents more. This suggests a comprehensive policy targeting both types of externalities may be designed with similar impact on urban and rural households. Congestion pricing, implemented at the national level, is actually more progressive than the current gas tax and other green financing policies, because households in congested areas on average earn significantly higher income than their counterparts in uncongested areas. Low-income households in large congested urban areas are the biggest losers under this financing scheme. Our analysis focuses on tax incidence and does not provide a full analysis of the benefits of our policies. For example though rural regions pay less under a congestion pricing scheme, they also receive fewer benefits towards their infrastructure from the lower HTF reimbursement. Also, improved air quality from lowered VMT could result in lower expenses towards pollution mitigation. (*70*) A full analysis would require taking all factors, both costs and benefits, into consideration. Another analysis might look at different revenue allocation methods that better represent the policies which are enacted. A Green VMT fee designed to address global climate concerns should have a nation-wide reallocation system while congestion pricing and emissions taxes a more localized revenue redistribution scheme. The revenue generated in a given region for these policies should be reallocated more heavily in that region so the targeted problems of congestion or pollution can be addressed. Some urban areas are more adversely affected by certain emissions, and so policy makers may be justified in charging higher emissions taxes in urban areas over rural regions. (*71*)

The exploratory analysis that was conducted by combining the regression analysis with the discrete choice modeling showed that as gas prices increased up to 300% more than current prices, households moved to more fuel efficient vehicles. Because households drove less and drove more efficient vehicles, emissions also declined. Since gas prices have never shown short term price hikes up to 300%, it is difficult to compare the results of the analysis with actual behavior patterns. The model results are however consistent with past research. Recent empirical evidence clearly shows households base their vehicle purchasing decisions on fuel costs. (*72,73,74,75,76)* Future research should extend the demand model in this thesis to consider the vehicle ownership of hybrid and electric vehicles and determine sensitivities of different vehicle owners to green transportation financing policies. Research can also better capture long term effects by utilizing more years of NHTS data. As more surveys are conducted, the analysis can produce more accurate results since households will experience greater vehicle turnover over longer time periods.

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