Evaluating Marginal-Cost Vehicle Mileage Fee with Econometric Demand Models

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1. Introduction

With the declining purchasing power of fuel tax revenue, emergence of hybrid and electric vehicles, more restrictive CAFE standard, and rapidly increasing cost, there is a major funding gap in surface transportation financing in the United States. Politicians, transportation professionals, and concerned citizens are actively seeking alternative revenue sources to supplement and/or replace fuel taxes. Among other options, vehicle mileage fee has emerged to be one of the strong candidates. Vehicle mileage fee, or distance-based user charge, has emerged as one of the leading alternatives/supplements to fuel taxes in recent surface transportation financing policy debates. Pay-As-You-Drive (PAYD) insurance implemented by the private sector charges users insurance premiums based on distance traveled. The public sector can implement vehicle mileage fee with various fee structures (flat or variable) for revenue generation (NCHRP Report 686, Zhang et al. 2009). For instance, mileage fees can be charged by vehicle fuel type, vehicle fuel efficiency, vehicle emission class, vehicle weight, facility type, time of day, and even in theory by income (Zhang and McMullen 2010, Zhang and Methipara 2011). The Netherlands and New York State in the U.S. have recently proposed and tested truck mileage fee systems based on GPS tracking technology. Also in the U.S., States such as Oregon (Whitty 2006) and Minnesota (Donath et al. 2003) have been exercising mileage-based fees on vehicles that cause significant road damage (e.g. heavy trucks). A national mileage fee experiment was recently completed under the leadership of the Public Policy Center at the University of Iowa with several thousand participating vehicles across the U.S. (Forkenbrock 2004, Hanley 2010). The feasibility of applying mileage fees to internalize a variety of negative externalities such as pollution emissions, greenhouse gas emission, road damage, and congestion is certainly attractive to economists, environmentalists, decision-makers, and many others.

The interests in congestion management and revenue generation have naturally led to the idea of marginal-cost vehicle mileage fee that can potentially achieve both objectives at once. It is hard to trace the origin of this idea, but it is certainly not new to this paper. With advance in Global Positioning Systems (GPS) and Automatic Vehicle Identification (AVI) technologies and less invasive (with respect to privacy and user burden) mileage tracking methods (e.g. on-line tracking with the storage of mileage information at zone-level only), marginal-cost vehicle mileage fee may just be the dreams of rational economists and revenue-seeking government in one reality. The Obama Administration has not announced support for mileage fee, but its stand and action on significantly increasing average vehicle fuel efficiency can only make mileage fee research and practices more imperative.

Despite tremendous enthusiasm about and apparent importance of marginal-cost mileage fee (MCMF), no previous study has estimated its magnitude for different vehicle types or its impact on vehicle ownership, vehicle miles traveled, government revenue, energy consumption, emissions, and equity. This research bridges this knowledge gap by answering the following three interrelated questions:

1. What is the total marginal cost of each mile traveled for different types of vehicle, not already borne by road users?
2. How do we analyze the multi-faceted impacts of MCMF with reliable data and models?
3. What are the impacts and their policy implications?

This paper computes vehicle mileage fee based on marginal cost of travel, internalizing various externalities such as congestion, infrastructure deterioration, and pollution emissions, and greenhouse gas (GHG) emissions. Multiple regression model and discrete choice models are developed based on 2009 NHTS data to analyze the impacts of the proposed marginal-cost vehicle mileage fee on vehicle ownership, fuel efficiency, vehicle miles traveled, energy consumption, emissions, and equity. In addition, the sensitivity of these impacts with respect to exogenous fuel price volatility is also estimated quantitatively.

2. Methodology

2.1. Marginal-Cost Mileage Fees

The socially optimal road user fee requires road users to pay all costs imposed on society, but not directly borne by them. The marginal-cost mileage fee, MCMF, we are proposing takes into account of the major driving externalities including pollution emissions, GHG emissions, road damage, and congestion. Based on the vehicle emission rate data, external aggregate costs of pollution emission and external maintenance cost, the external costs of the four categories discussed are calculated for each vehicle make/model. After combining all four types of external costs, we found that MCMF varying by vehicle make and model ranges from 0.077$/mile to 0.091$/mile.

2.2. Model Development

The 2009 National Household Travel Survey (NHTS), the most recent authoritative source of travel behavior information at the U.S. national level, is used as one of the main data source for modeling purposes. In addition, vehicle characteristics for each make and model such as purchase price, horse power, tow capacity, comfort, and safety ratings are obtained from the 2009 Consumer Reports.

Household-level Multiple Regression Model

Household vehicle miles travel is affected by the fuel cost per mile, land use, household income, vehicle ownership, and household socio-demographic factors. Therefore, a household-level multiple regression model with annual miles travel as the dependent variable can be developed, while the independent variables are shown in the model estimation results (see Table 1).

The results show that fuel cost has negative relation with the household vehicle miles travel, which indicates that high fuel cost would prevent household from driving more. Based on the regression data set and the model estimation, we could find that the household’s fuel cost elasticity of VMT ranges from -1.273 to -0.12. For most individuals, a one-percent increase in per-mile driving cost would result in a less than one-percent reduction in VMT.

Table 1. Regression Model Estimation Results

Dependent Var: VMT	Coefficient
Substitute	-0.0307**
Fuelcost	*-2.6628***
*Substitute*Fuelcost*	*0.0102***
lncome	*-0.1526***
*Fuelcost*Income*	*0.1777***
Vehicle Count	*0.8089***
Driver Count	0.1610**
Household Size	0.0537**
Msa_1	0.0568**
Msa_2	0.0154
Msa_3	-0.0372**
MaleRespodent	0.1161**
Resp_Age16-34	0.3291**
Resp_Age35-64	0.2610**
Resp_Americaof African	-0.1065**
Resp_Asian	-0.1424**
Resp_Hispanic	0.0509
Population Density (1000 persone/square mile)	-0.0281**
Constant	12.0107**
R-Square	0.7692

Notes: Italic font indicates the independent variable is logged.
** indicates the variable is significant at 95% confidence interval

Household Vehicle Ownership Model

In order to better describe the possible impact of the mileage fee or gasoline price change on household vehicle ownership decisions from a long-term view, two independent discrete choice models, vehicle Number choice model and vehicle Type choice model, are developed, taking into account of households heterogeneity. In this paper vehicles are classified into seven types: Small Car, Large Car, Small SUV, Large SUV, Small Pickup, Large Pickup and Minivan. The variables used in the models are shown in the estimation results. In our research, the discrete choice analysis focused on households with no more than four vehicles, due to the fact that the number of possible vehicle bundle will increase exponentially with the increase of the vehicle number.

Table 2 represents the model estimation results of household vehicle number choice. In the vehicle number choice model, household with no vehicles are set as reference for model estimation, and the heterogeneity of households' response to fuel price is reflected through the estimation results of the mean and the standard deviation of the coefficient of fuel price. The estimation results of the fuel price show that as fuel price increases people are not likely to own three and four vehicles, while they still buy one and two vehicles. One reason for the outcome might be that although fuel price increases, people still need vehicles to commute and for daily life. The insignificance of the fuel price might be the lack of variation in fuel price which in our dataset only varies by state.

Table 2 Household Vehicle Number Choice

	One Vehicle	Two Vehicle	Three Vehicle	Four Vehicle
Variable	Coefficient	Coefficient	Coefficient	Coefficient
Constant	-3.040**	-8.990**	-14.300**	-18.800**
Driver Count	2.860**	5.560**	7.300**	8.240**
Resp_Age16~34	-0.215**	0.488**	0.717**	1.110**
Resp_Age35~64	0.021	0.627**	1.140**	1.570**
Children Count/Household Size	0.052	0.504**	-0.137	-0.944**
Fuel Price(Mean)	0.260*	0.048	-0.307	-0.545*
Fuel Price(St.Dev.)	0.003	0.006	0.002	0.108
Income (100,000$)	2.120**	3.740**	4.360**	4.680**
MSA>1 million with Rail	0.063	-0.155	-0.434**	-0.670**

MSA>1 million without Rail	0.321**	0.169**	-0.194**	-0.522**
MSA<1 million	0.206**	0.089	-0.213**	-0.576**
Resp_American of Afrian	-0.971**	-1.300**	-1.160**	-1.450**
Resp_Asian	0.017	-0.210	-0.168	-1.000**
Resp_Other Race	-0.526**	-0.603**	-0.508**	-0.541**
Male Respondent	-0.287**	0.155**	0.184**	0.320**
Own House	1.260**	2.430**	2.990**	3.580**
Density (100 persons)	-0.104**	-0.193**	-0.257**	-0.329**

** indicates the variable is significant at 95% confidence interval
* indicates the variable is significant at 90% confidence interval

In the vehicle type choice model, four mixed logit models with the fuel cost independently normally distributed are developed separately for one-, two-, three-, and four-vehicle households. Due to the space limitation, only one-vehicle type choice model estimation is represented in Table 3.

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

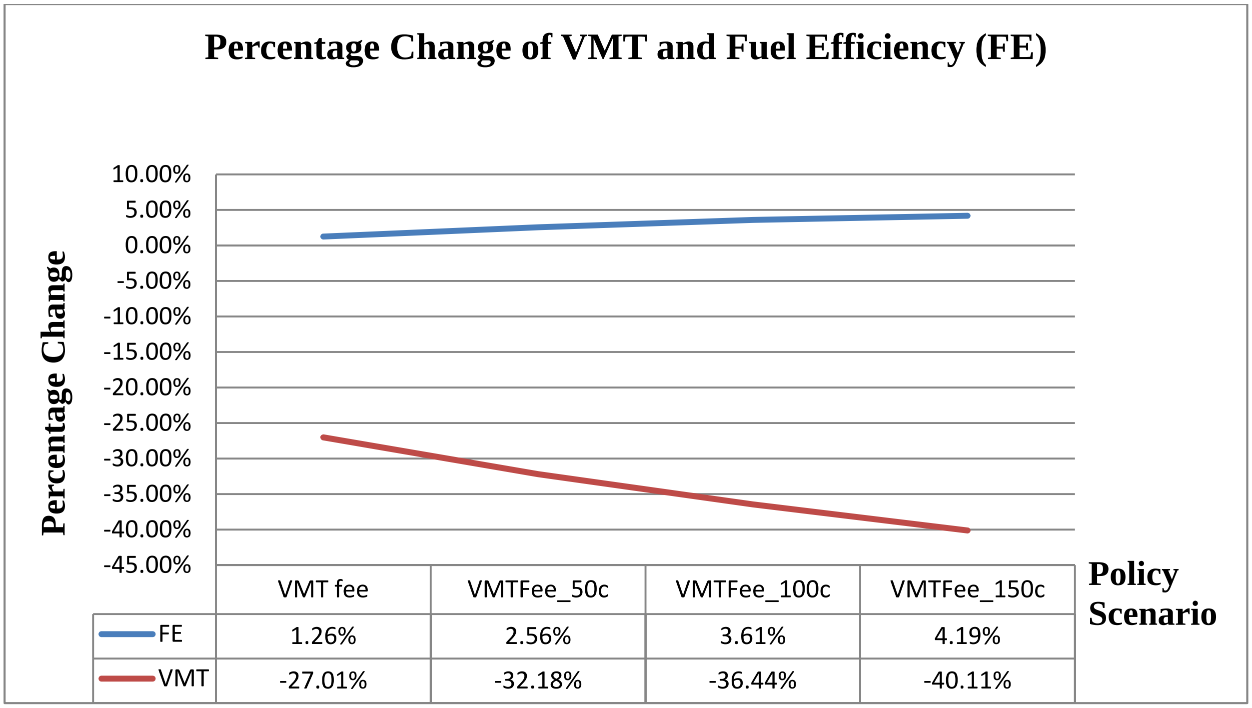
	Small Car	Large Car	Small SUV	Large SUV	Small Truck	Large Truck	Minivan
Variables	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Fuel Cost (Mean)	-0.46100**						
Fuel Cost (Std.dev)	1.06000**						
Vehicle Price*Income	0.00032**						
Interior Room	0.00991**						
Vehicle Price	-0.00015**						
Horse Power	0.00952**						
Tow	0.000	0.000	-0.00011	-0.00071**	-0.0001	-0.00014**	-0.00038
Income(100,000$)	0.259*	-1.730**	0.908**	-2.420**	0.347	-2.110**	0.0000
Household Size	-0.948**	-0.559**	-0.655**	0.151**	-0.697**	0.022	0.0000
MSA_1	2.270**	0.176	1.030**	-1.550**	-0.701**	-3.080**	0.0000
MSA_2	0.947**	0.124	0.310**	-0.672**	-0.699**	-1.290**	0.0000
MSA_3	0.577**	0.105	0.191	-0.627**	-0.520**	-1.220**	0.0000
Constant	1.060	1.770	0.416	4.490*	1.240	1.440	0.0000

** indicates the variable is significant at 95% confidence interval
* indicates the variable is significant at 90% confidence interval

The estimation results show that all the alternative specific variables are significant at 95% confidence level. The coefficient of the fuel cost represents that 66.8% of the distribution has negative relations with the fuel cost, indicating households prefer vehicles with less fuel cost, and 33.2% of the distribution has positive relations with fuel cost. The coefficients estimation for vehicle characteristics indicates that households have a significant preference for vehicles that are cheaper (Vehicle Price -0.00015), more comfortable (Interior room 0.00991), and more powerful (Horse Power 0.00952). The positive coefficient for the interaction variable, Vehicle Price*Income, indicates higher-income households are less sensitive to vehicle prices.

3. Policy Analysis

To examine the impact of the proposed mileage fee, we replace the federal tax with the marginal-cost mileage fee (MCMF). In order to evaluate the effectiveness of the proposed transportation financing policies comprehensively with VMT demand model and vehicle ownership model, a number of performance measures are developed such as VMT reduction, gasoline consumption, average fuel efficiency of households who alter their vehicle combinations under proposed policies, consumer surplus change by income groups, GHG emission, as well as vehicle emission of the pollutants NOX, CO, PM and VOC.



	VMT fee	VMTFee_50c	VMTFee_100c	VMTFee_150c
FE	1.26%	2.56%	3.61%	4.19%
VMT	-27.01%	-32.18%	-36.44%	-40.11%

* MCMF+50c, MCMF+100c, MCMF+150c indicate the extended MCMF fee policies with increases in external fuel prices by 50, 100, and 150 cents/gallon respectively.

Figure 1 Vehicle Fuel Efficiency and VMT Changes under MCMF

If MCMF that incorporates the external costs of pollution emissions, GHG emissions, congestion, and road provision/preservation is imposed on all households, the average driving cost per mile would increases by almost 60%, and the average VMT per household would decreases by 27%. In addition, we also explore the impacts of MCMF with exogenous fuel price increasing by 50 cents/gallon, 100 cents/gallon and 150 cents/gallon respectively (Figure 1). Figure 1 shows that the vehicle use is much more sensitive to MCMF and exogenous fuel price increases than vehicle ownership, with minor increase by 4.2% in vehicle fuel efficiency.

Analysis results indicate that marginal-cost vehicle mileage fee can reduce energy consumption and pollution/GHG emissions by about a quarter. These sustainability benefits are even more significant if fuel prices continue to increase. As expected, lower-income households (consumer surplus decrease by 3.6% without considering the benefits from revenue redistribution) would be hurt more than higher-income households (1.3%). It is hypothesized that if the much higher revenue (four to five times higher than fuel tax revenue) from marginal-cost vehicle mileage fee is properly redistributed through strategized investment and/or subsidies to the poor, all can benefit. This hypothesis remains to be tested in future research. It should also be pointed out that the NHTS data used for model development are cross-sectional in nature, and do not reflect vehicle ownership and use behavior shifts over time. Future research may collect and develop models based on longitudinal behavioral process data under driving cost volatility for policy analysis related to MCMF or other forms of vehicle mileage fees.

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