COMPARISON OF SOCIOECONOMIC IMPACTS OF MARKET-BASED INSTRUMENTS FOR MOBILITY MANAGEMENT UNDER UNCERTAINTY

By

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To my Mom, the Late Bernice Oye Sakyi, who first taught me the basic principles of economics

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COMPARISON OF SOCIOECONOMIC IMPACTS OF MARKET-BASED INSTRUMENTS FOR MOBILITY MANAGEMENT UNDER UNCERTAINTY

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This study compared the socioeconomic impacts of three market-based instruments: gasoline tax, mileage fee and tradable credit schemes, for mobility management. The National Household Travel Survey (NHTS) data for 2009 was used for the analysis. A hypothetical case study where FDOT intends to reduce the total vehicle miles by 15% in Florida was targeted.

A deterministic household travel demand function was developed and used to examine the socioeconomic impact of the three market-based instruments. It was found that all three instruments are capable of achieving the hypothetical 15% reduction of total travel demand in Florida. However, they generate different amounts of revenue and impose different socioeconomic impacts on Florida residents. Gasoline tax and mileage fee schemes charge travelers more to discourage their travels to achieve the control target. Consequently, the government receives much more revenue. At the same time, the schemes hurt residents more and do more harm to the poor than the rich. The tradable credit scheme generates the least revenue for the government but has a less regressive impact on residents.

Secondly, we assumed that the household travel demand function is uncertain and conducted similar analysis to determine the socioeconomic impact of the three instruments. The

three policy instruments were all capable of reducing the VMT by 15% on average. However, the gasoline tax and mileage fee policies were found to have a lower success rate and the revenue generated was variable. For the tradable credit scheme, the success rate was found to be 100% and the revenue generated fixed; the socio economic impact was found to be similar to that obtained under the deterministic travel demand.

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Traffic congestion is perhaps one of the most severe problems threatening the economic and social wellbeing of many societies. According to the Texas Transportation Institute (TTI), in 2011, congestion caused urban Americans to travel an extra 5.5 billion hours and to purchase an extra 2.9 billion gallons of fuel amounting to a total congestion cost of $121 billion. If this trend is not curbed, it is estimated that by 2020, travelers will be delayed an extra 8.4 billion hours and purchase an extra 4.5 billion gallons amounting to a total congestion cost of $ 199 billion.

To avert this situation from degenerating, transportation planners and engineers need a concerted effort. To this end, the Federal Highway Administration (FHWA) has been embarking on different strategies to reduce the congestion on the nation's roads. These strategies involve, improving services on existing roads, pricing, adding capacity, better work zones, travel options, and traveler information.

This research focuses on reducing congestion using pricing schemes. Congestion pricing, also called value pricing is a way of harnessing the power of the market to reduce waste associated with traffic congestion (FHWA, 2006). There are four main types of pricing strategies that the FHWA have adopted, namely, variably priced lanes, variable tolls on entire roadways, cordon charges, and area-wide charges.

The variably priced lanes includes express tolls and High Occupancy Toll (HOT), and the latter involves charging low occupancy vehicles tolls for using HOT lanes while high occupancy vehicles (HOVs), public transit buses and emergency vehicles are allowed to use the HOT lanes free of charge or at a reduced rate. The variable tolls on entire roadways involve changing a flat toll rate on existing roads to a variable toll schedule such that tolls are higher during peak travel

hours and lower during off-peak or shoulder hours. Cordon pricing involves charging a fee to enter a congested area. The area-wide pricing scheme (also called the mileage fee pricing scheme) involves per-mile charges.

Other methods of reducing congestion are by increasing fuel or gasoline charges and by using tradable credits. The gasoline charges, mileage fee, and tradable credits are generally market based instruments. This research compares the effectiveness of these market based instruments in reducing the total travel demand of travelers in Florida State by 15%. The comparison is done by assuming a deterministic household travel demand followed by a stochastic household travel demand.

1.2 Objective

The main objectives of this research are to determine:

- The social economic impacts of market-based mobility management instruments: i.e. gasoline tax, mileage fee and tradable credits in regulating Vehicle Miles Travel (VMT) in Florida.
- To determine the most effective market-based mobility management instrument in regulating VMT when the individual household demand functions are assumed to be stochastic

1.3 Outline of Research

To achieve the above objectives, Chapter 2 presents a literature review on market based mobility management instruments in curbing congestion, Chapter 3 gives a detailed methodology, Chapter 4 gives the details of the data and model calibration for our analysis, Chapter 5 presents the impact analysis, and Chapter 6 gives the conclusions and recommendations.

CHAPTER 2
LITERATURE REVIEW

There are generally two approaches transportation planners/engineers employ to ameliorate congestion: increasing road capacity (supply) or reducing traffic (demand). The former has been traditionally used in many instances, however, from "the fundamental law of highway congestion" as suggested by Downs, Antony (1962, 1992), increasing capacities usually induce new demands; which ultimately reverts the highway to its originally congested condition. In view of this, current focus has been on the demand management of traffic congestion; this involves using market-based instruments for congestion mitigation. Broadly, market-based instruments can be classified into two classes, i.e. price and quantity based. The price based i.e. congestion pricing, which forms the basis of the seminal work by Pigou (1920), charges vehicles using congested roads to bear a tax equal to the difference between marginal social and marginal private cost involved. Economic theory suggests congestion pricing as an efficient pricing strategy that requires the users to pay more for a public good, thus increasing the welfare gain or net benefit for society. The main idea is to charge travelers the marginal external costs that their trips impose to the society to reduce traffic congestion or increase social welfare.

Policy makers have used several pricing strategies in curbing congestion. The most commonly used is the gasoline tax, which serves both as a road user fee and a means to ameliorate congestion. Morrison (1986) and Small et al. (1989) provide an extensive literature review on optimal road user fees both under congested and uncongested circumstances. It must be noted that road maintenance cost is the primary component of road user fees while the congestion cost is a results of flow exceeding capacity (Small et al. (1989)). Increasing the gasoline tax is mostly unappealing given how society sees the gasoline tax and thus it receives a lot

of resistance in implementation. The resistance has been mainly focused on perceived inequality or unfairness of the tax.

The Federal Highway Administration (FHWA) has been focusing on high-priority efforts to help reduce congestion in the United States. There are four main types of pricing strategies that the FHWA has adopted, namely, variably priced lanes, variable tolls on entire roadways, cordon charges, and area-wide charges. The variably priced lanes include express tolls and High Occupancy Toll (HOT) and the later involve charging low occupancy vehicles tolls for using HOT lanes while high occupancy vehicles (HOVs), public transit buses and emergency vehicles are allowed to use the HOT lanes free of charge or at a reduced rate. The variable tolls on entire roadways is involve changing a flat toll rate on existing roads to a variable toll schedule such that tolls are higher during peak travel hours and lower during off-peak or shoulder hours. Cordon pricing involves charging a fee to enter a congested area. Places that have operationalized such pricing schemes include Singapore in 1975, Central London in 2003, and central Stockholm on a trial basis in 2006. The area-wide pricing scheme (also called the mileage fee pricing scheme) involves per-mile charges. In the United Sates, there is growing push for the implementation of the mileage fee policy mainly because of the low revenue generated from the fuel tax to fund road projects. Oregon tried the mileage fee policy in 2003, under this scheme truck operators reported their in and out-of-state mileage and they were exempted from the state fuel tax (TRB Committee for the Study of Long-Term Viability of Fuel Taxes for Transportation Finance (2006)). Other studies that focused on Oregon include Whitty and Imholt (2005), Whitty et al. (2006), and Zhang et al. (2009).

Due to the perception of inequity associated with congestion pricing, attempts have been made to develop a more equitable pricing scheme. Major proposals have been on developing an

appealing Pareto-improving congestion pricing with revenue redistribution schemes. Key researchers that have worked in this area include Lawphonpanich and Yin (2010), Song et al., (2009), Lui et al. (2009), Nie and Liu (2010), and Guo and Yang (2010). Despite these proposals, there are still resistances since the government is seen as an objectionable tax collector, and proving their revenue-neutrality is difficult for people to believe.

In view of this, focus is now turning to the demand management of congestion. In this proposition, the government fixes the quantity of travel demand, and then assigns mobility rights equally to all individual travelers or inhabitants ensuring that equity is revealed. The two common forms of quantity based instruments are the road space rationing and cap-and-trade schemes. In the road space rationing, the government restricts private cars from using the road network on certain days with the aim of ensuring fairness and reducing congestion. Example of cities that have implemented such a scheme is Mexico and Sao Paulo where the number of vehicles is controlled through plate-number-based space rationing. In this system, the quantity of cars on the road is controlled by the authority allowing certain number plates to use the road facility on a specified day. However this scheme has been found to be short-lived, has a perverse incentive of second-car ownership, and has been proven to be unsustainable (Davis (2008); Mahendra (2008); Wang et al. (2010)).

In the cap-and-trade schemes i.e. tradable permit schemes and tradable credit schemes, the state agency or government distribute a specified quantity credits (cap) by first selling them to potential travelers. Thereafter, credits can be traded among travelers and the price is determined by the market through free trading. By deciding the initial credit distribution and the subsequent credit charging scheme, the agency can achieve its policy goal. Such a scheme has been recently studied by Yang and Wang (2011), Wang et al. (2012), Goddard (1997), Verhoef

et al. (1997), Viegas (2001), Kockelman and Kalmanje (2005), and Raux (2007). Tradable credit schemes offer several advantages. First, the credit market allows those who value travel time savings less to be directly compensated by selling credits to those who value them more. This mechanism promises simpler and fairer distribution of the benefits from congestion reduction. Secondly, as no transfer of wealth takes places between travelers and the authority, the payment made to acquire credits is less likely to be perceived as a tax. Finally, when justified, the welfare effects of the schemes on individuals may be controlled by the way the credits are distributed.

CHAPTER 3
METHODOLOGY

To achieve the objectives of this study, a hypothetical scenario where Florida DOT plans to reduce the total vehicle miles traveled by Florida residents by 15% while maintaining at least the current level of revenue from the existing state gasoline tax is considered. The 2009 NHTS data for Florida was used for the analysis; it was first cleaned, and then a travel demand function which relates the total annual VMT by a household to its social characteristics, the attributes of transportation services, and the cost/price of travel was established with the aid of Statistical Product and Service Solutions (SPSS) version 17 software. Thereafter, a scenario in controlling the VMT by implementing three policy instruments i.e. increasing state gasoline tax, replacing the state tax with mileage fees and the use of tradable credit scheme was considered under a deterministic household travel demand function. The socioeconomic implications of these policy instruments were then accessed. A similar analysis was further done considering that the individual travel demand functions are stochastic and FDOT still desires to reduce the total VMT by 15%. Implementation of the socioeconomic indicators was all done with the aid of MATLAB version R2011b software.

The implementation of the state gasoline tax and replacement of the state tax with mileage fees are fairly straightforward. However, the use of a tradable credit scheme requires further explanation. The following is an explanation of how the tradable credit scheme was implemented. It is first assumed that the state agency first allocates travel credits equivalent to 85% of the current VMT to eligible individual households and then collects one credit for each mile traveled. To maintain the current level of revenue, the initial price of the credit is equal to the current revenue divided by 85% of the current VMT. Subsequently, the state agency will create a credit market that enables credit trading among households. If a household travel need is

more than the credits allocated, they will purchase more from the market or give up their travel. Similarly, households with excess credits will either sell their credits in exchange for money or give them to environmental agencies. It must be noted that during this stage, the government or stage agency does not interfere with the credit market but only act as a manager in monitoring the system. It is assumed that the transaction cost is negligible; thus the price of the credit is mainly determined by the supply and demand of credits on the market (Yang and Wang, (2011)).

Based on the travel demand function, the changes in consumers' surplus, revenue and social welfare across income groups was estimated. The changes in consumers' surplus, revenue and social welfare are estimated approximately as follows:

$\Delta CS = 0.5 \times (EQ_1 - EQ_2) \times (TM_1 + TM_2)$

$\Delta Revenue = (StateGasTax_2 \times TM_2 - StateGasTax_1 \times M_1)/\ AvgMPG$ (For Gas Tax)

$\Delta Revenue = (VMT\_Fee \times TM_2 - StateGasTax_1/AvgMPG) \times TM_1$ (For Mileage Tax)

$\Delta SW = \Delta CS + \Delta Revenue$

Where,

ΔCS = Change in consumers' surplus ($)

$\Delta Revenue$ = Change in Revenue ($)

ΔSW = Change in Social Welfare ($)

EQ_1=Current equivalent price or cost of travel $/mile

EQ_1=New equivalent price or cost of travel $/mile

TM_1=Annual miles driven by household under current price (mile)

TM_2=Annual miles driven by household under new price (mile)

$StateGasTax_1$=Current state (and local) gasoline tax in $/gallon

$StateGasTax_2$=New state (and local) gasoline tax in $/gallon

$AvgMPG$=Average miles per gallon in mile/gallon

VMT_Fee=The mileage fee in $/mile

For the tradable scheme, the change in consumers' surplus is explained in the following example. Assuming in a mileage fee policy a flat fee of 3.7 cents/mile is required to achieve a 15% VMT reduction, then using Figure 1(a), the area *abcd* represents the change in consumers' surplus-where 1.6 cents/mile is the current equivalent travel price. Suppose government intends to distribute credits per households at a price of 1.7 cents/credit to maintain the current revenue, and the market-clearing price for each credit is 3.7 cents/credit (this is determined from the market demand function i.e. the sum of the individual household demand functions). Now, assuming each household is allocated 1000 credits and considering a household whose demand is 800 vehicle miles at 3.7cents/mile. The surplus this household receives from travel in this case is shown by area *oefc* in Figure 1(b). Additionally, the household sells the extra 200 credits to the market and earns an income of $4.0 (i.e. (0.037-0.017)x 200). Therefore, the change in consumers' surplus for this household under the credit scheme will be Area *oefc* + $4.4 – Area *oab*. For a household with a demand of more than 1000 vehicle miles, it will be better off purchasing additional credits from the market. The change in consumers' surplus is calculated similarly to the forgoing with the only difference been that it incurs additional credit expense instead of earnings.

The calculation of the socioeconomic measures under uncertainty in the travel demand function follows a similar procedure. However, for the tradable credit scheme, it must be noted that the market clearing price changes at each sample. Details are provided in Chapter 5.

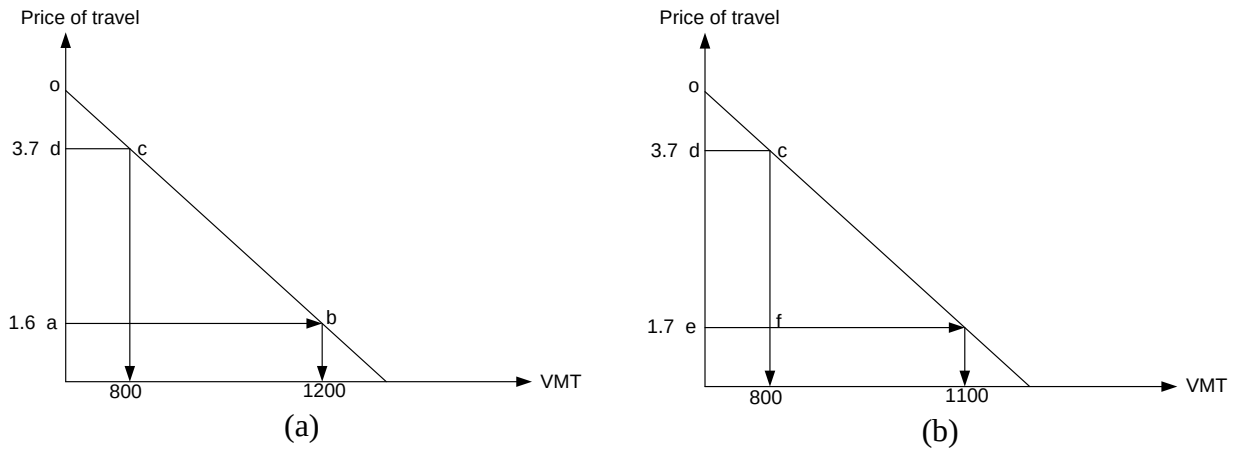

Figure 3-1. Change in consumers' surplus (a) mileage fee (b) tradable credits.

CHAPTER 4
DATA AND MODEL CALIBRATION

4.0 Data Description

The 2009 NHTS data for Florida was used for this study. It consists of four files: household, person, trip and vehicle files i.e. 15,884 household entries, 30,952 person entries, 114,910 trip entries and 29,457 vehicle entries in the dataset. Analysis was carried out at the household level; therefore, some attributes from the vehicle and person data files had to be integrated into the household data file which resulted in a total of 13,086 household data used for the analysis. The original data set does not provide specific income values, thus, an averaging value of income range of each income category was used for the model calibration and analysis. The BESTMILE (best estimate of annual miles) and EIA fuel efficiency (measures from Energy Information Administration) were used instead of ANNMILES (self-reported annualized mile estimate) and EPA (Environmental Protection Agency) fuel efficiency. Mamun (2012) provides details of the data cleaning in his dissertation.

Following the data cleaning, a statistical analysis was run with the aid of SPSS version 17 statistical software. Table 4-1 presents a summary of the descriptive statistics; from the table, we can observe the following: the average household vehicle ownership increases with increase in income, the average fuel efficiency of vehicles are similar among different income groups, and the total annual miles driven per household increases with increase in income.

4.1 Model Calibration

Multiple regression models have been found to be capable of capturing real life behavior, and are easy to execute and effective for policy analyses. A multiple regression model was adopted in this research following a similar model adopted by McMullen et al. (2010). In their model, total annual miles driven by a household, i.e., travel demand of the household, is assumed

to be a function of social characteristics of the household and attributes of transportation services. The household vehicle ownership is assumed to be fixed and a log-log linear regression model is used to avoid a negative value of vehicle miles driven by a household. The functional form below was used for the analysis:

$$In(TM) = \beta_o + \beta_1 \times In(EQ) + \beta_2 \times In(hhtinc) + \beta_3 \times In(hhvcnt) + \beta_4 \times U + \beta_5 \times In(hhtinc) \times In(EQ) + \beta_6 \times SUB + \beta_7 \times In(EQ) \times SUB + \beta_8 \times wrkcnt + \beta_9 \times hhchild$$

Where,

TM = Total annual miles driven by all vehicles in a household (mile)

EQ = Equivalent travel price or cost per mile ($/mile)-estimated as follows: $\sum_i EQ_i \times EQ_i / \sum_i EQ_i$

where $EQ_i = \frac{NetGasPrice + StateGasTax}{MPG_i} + VMTFee$, (i represents individual vehicles in a household)

hhtinc = Total annual household income ($)

hhvcnt = Household vehicle count

U = dummy variable-1 if the household is located in urban area, 0 otherwise

SUB = dummy variable-1 if the household has different types of vehicles, i.e. car, van, SUV, truck and RV, 0 otherwise

wkrcnt = Number of workers in the household

hhchild = Number of children in the household

Table 4-1. Descriptive Statistics by Income Group

Income Group	Income range	Household			No. Veh. Per HH	Avg. veh. MPG per HH	Total annual VMT per HH
		Total HH	Rural HH	Urban HH			
Group 1	$0-$19,999	2119	475	1644	1.40	20.64	12187
Group 2	$20,000-$39,999	3288	737	2551	1.64	21.04	15926
Group 3	$40,000-$59,999	2468	537	1931	1.91	21.49	21035
Group 4	$60,000-$79,999	1800	373	1427	2.16	21.78	24650
Group 5	$80,000-$200,000	3411	653	2758	2.42	21.46	29629
Overall Avg.	-	-	-	-	1.93	21.27	21056

Table 4-2. Estimated Model

Variable Name	Coefficient	Std. error	t-statistic
Constant	-2.4787	0.6472	-3.8298
In(EQ)	-5.4067	0.3416	-15.8274
In(hhtinc)	0.7612	0.0620	12.2745
In(hhvcnt)	0.9188	0.0196	46.9485
U	-0.1821	0.0147	-12.3627
In(hhtinc)*In(EQ)	0.3449	0.0327	10.5518
SUB	1.6881	0.1163	14.5149
In(EQ)*SUB	0.7499	0.0607	12.3453
wrkcnt	0.1509	0.0084	18.0693
hhchild	0.1023	0.0079	12.8797

For model calibration, the equivalent travel price or cost per mile, i.e., *EQ*, in the above is estimated as the net gasoline price plus the federal and state taxes per gallon divided by the miles per gallon of the vehicle in a household. If the household owns multiple vehicles, the cost per mile is a weighted average using the total annual miles driven by each vehicle as the weight. The model is calibrated with the clean data set, and the coefficients of the model are presented in Table 4-2. The adjusted R-square is 0.56, and all the coefficients have the correct sign and are statistically significant at the 99% confidence interval.

The calibrated demand model can be used to predict new demands via the changes in the equivalent travel cost caused by those three instruments. More specifically, the equivalent travel or cost per mile will increase with the increased state gasoline tax. Under the mileage fee policy, the state tax becomes zero and the mileage fee will be directly added to the equivalent travel cost per mile. With the tradable credit scheme, the state tax is also zero and the market-clearing credit price is added to the equivalent travel cost per mile.

The demand elasticity is calculated using the expression below and the results shown in Table 4-3. From the elasticity values, we can observe that lower income people are more sensitive to fuel cost than those with higher incomes, and households with only one type of vehicle are more sensitive than households with multiple types of vehicles.

$$e = (\Delta M/M)/(\Delta PM/PM) = (\delta M/\delta PM) \times (PM/M) = \beta_1 + \beta_5 \times In(hhtotinc) + \beta_7 \times SUB$$

Table 4-3. Elasticity by Income Group Based on Average Income

Income groups ($)	Avg. Income ($)	Elasticity with SUB	Elasticity without SUB
$0-$19,999	12705	-2.02	-2.19
$20,000-$39,999	30290	-1.59	-1.85
$40,000-$59,999	50365	-1.32	-1.67
$60,000-$79,999	70847	-1.10	-1.56
$80,000-$200,000	130457	-0.85	-1.35

CHAPTER 5
IMPACT ANALYSIS

The focus of the impact analysis will be on changes in consumers' surplus, revenue and social welfare. The change in consumers' surplus captures the impact of a policy on the household whereas the change in revenue gives an estimate of the feasibility of the policy. The total change in social welfare is the sum of the change in consumers' surplus and change in revenue. The foregoing is the analysis of the impact of the three policies on the household with different income groups assuming the state agency intends to reduce the total VMT by 15%.

5.1 Comparison of Schemes under Deterministic Household Travel Demand

A comparison between the three policy instruments is made assuming that the individual household demand function is deterministic. Appendix A shows a MATLAB program written to conduct the impact analysis.

5.1.1 Gasoline Tax

In 2009, the average state (and local) gasoline tax in Florida was 34.5 cents/gallon. To reduce the VMT by 15%, the tax needs to be 58.5 cents/gallon, this may be considered as too high and politically unacceptable. However, many OECD countries (Wikipedia, (2012)) have comparatively higher taxes.

From the analysis, government will generate additional $2.28 million revenue if such a tax is implemented. Furthermore, the total change in consumers' surplus will be -$2.70 million, while the total change in social welfare will be -$0.42 million. The impact on households in the different income category is summaries in Table 5-1.

From Table 5-1, it can be seen that all the changes in consumers' surpluses for the various income groups are negative. Furthermore, it can be seen from the percentage change in

consumers' surplus that the lower-income groups suffer more than those in the higher income groups.

It must however be noted that although the model predicts that an increase in tax by about 24 cents/gallon will cause a 15% reduction in VMT, this may not be the real case as other factors not captured in the model may cause a lesser reduction in VMT.

Table 5-1. Average Changes in Consumers' Surplus, Revenue and Social Welfare (Gasoline Tax)

Income group	Avg. change in consumer surplus ($)	Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0-$19,999	-106.44	-0.84	78.01	-28.44
$20,000-$39,999	-150.32	-0.50	119.45	-30.87
$40,000-$59,999	-200.26	-0.40	166.53	-33.73
$60,000-$79,999	-247.25	-0.35	212.23	-35.02
$80,000-$200,000	-306.57	-0.23	273.31	-33.25

5.1.2 Mileage Fee

The flat-fee structure was implemented in our mileage fee analysis. Currently, the average gasoline tax in Florida is 52.9 cents/gallon with the federal tax and 34.5cents/gallon without the federal tax, i.e., the sum of the state and county taxes. Using 21 miles per gallon (MPG) as the average fuel efficiency of vehicles in Florida, the current state gas tax of 34.5 cents/gallon is equivalent to 1.64 cents/mile, if all other factors remain the same. To obtain a revenue-neutral impact fee and fees for other purposes, the model is executed multiple times, and the resulting socioeconomic impacts are summarized in Table 5-2. From Table 5-2, it can be seen that the revenue neutral flat mileage fee is 1.61 cents/mile. Also the mileage fee required to reduce VMT by 15% is 3.70cents/mile. Details of the socioeconomic impacts of 1.61 and 3.70 cents/mile across different income groups are presented in section 5.1.3 and section 5.1.4 respectively.

5.1.3 Mileage Fee of 1.61 Cents/Mile (Revenue-Neutral Fee)

For the revenue neutral mileage fee i.e. 1.61 cents/mile, it can be observed from Table 5-3 that the average percentage change in consumers' surplus as a percentage of income across the across the various income group is negligible. Although there is a general increase in the average change in consumers' surplus as the income levels increases, it can be observed that those in the highest income groups do have negative values.

Table 5-2. Changes in Consumers' Surplus, Revenue, Social Welfare and VMT under different Mileage Fees

Mileage fee (cents/mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in social welfare ($)	% VMT reduction
1.60	3,818	-18,364	-14,546	0.92
1.61	28,989	3,518	32,508	1.00
1.62	54,141	25,366	79,507	1.08
1.63	79,272	47,179	126,450	1.16
1.65	129,480	90,701	220,180	1.32
1.70	254,640	198,910	453,550	1.71
2.00	995,610	830,760	1,826,400	4.02
2.50	2,195,100	1,822,300	4,017,400	7.60
3.00	3,354,900	2,744,800	6,099,700	10.89
3.50	4,479,500	3,606,100	8,085,600	13.93
3.70	4,920,300	3,935,100	8,855,400	15.08

Table 5-3. Average Changes in Consumers' Surplus, Revenue and Social Welfare (Mileage Fee=1.61cents/mile)

Income group	Avg. change in consumer surplus ($)	Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0-$19,999	1.92	0.02	0.35	2.28
$20,000-$39,999	3.21	0.01	1.09	4.30
$40,000-$59,999	5.25	0.01	2.85	8.10
$60,000-$79,999	8.30	0.01	5.41	13.71
$80,000-$200,000	-3.97	0.00	-5.15	-9.13

5.1.4 Mileage Fee of 3.70 Cents/Mile

The impact of a flat mileage fee of 3.70 cents/mile is presented in Table 5-4. It can be seen that the average change in consumers' surplus for such a fee will generally lead to negative changes in consumers' surpluses for all income groups i.e. they are regressive. From the average

change in consumers' surplus as a percentage of income, it can be seen that the lower income groups are more impacted by such a fee than the high income groups.

Table 5-4. Average Changes in Consumers' Surplus, Revenue and Social Welfare (Mileage Fee=3.70 cents/mile)

Income group	Avg. change in consumer surplus ($)	Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0-$19,999	-190.99	-1.50	126.57	-64.42
$20,000-$39,999	-273.56	-0.90	201.10	-72.46
$40,000-$59,999	-369.38	-0.73	289.01	-80.36
$60,000-$79,999	-462.59	-0.65	377.18	-85.41
$80,000-$200,000	-548.78	-0.42	473.02	-75.76

Compared to the gasoline tax policy, the mileage fee policy achieves the control target with slightly higher impacts. Moreover, although its distributional effects look similar, the mileage fee policy is slightly more regressive.

5.1.5 Tradable Credit

The explanation to the tradable credit system given in chapter 3 assumed a linear demand function; however, the demand function for our analysis is nonlinear. A linear approximation of the demand function was used and found to be a good approximation for the foregoing analysis. Considering a tradable credit policy where the total credits equal to 85% of the current VMT are uniformly distributed among 13086 households in our sample. Each household therefore needs to pay 1.73 cents of credits in order to allow the state to maintain its current level of revenue. The distributional impacts of this scheme are shown in Table 5-5. It can be observed from the average change in consumers' surplus that those in the lower income bracket have positive and higher values. Also form the average change in consumers' surplus as percentage of average income, there is a similar trend where those in the lower income group do have higher positive values.

Table 5-5. Average Changes in Consumers' Surplus, Revenue and Social Welfare (Tradable Credit)

Income group	Avg. change in consumer surplus ($)	Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0-$19,999	133.84	1.05	46.90	180.74
$20,000-$39,999	65.93	0.22	47.48	113.40
$40,000-$59,999	-17.82	-0.04	62.87	45.05
$60,000-$79,999	-91.91	-0.13	57.27	-34.64
$80,000-$200,000	-202.86	-0.16	58.63	-144.23

5.1.6 Overall Comparison under Deterministic Household Travel Demand

Table 5-6 shows the total changes in consumers' surplus, revenue, social welfare, their standard deviation, and VMT under the three instruments for the different schemes. While Table 5-7 shows the average changes in consumers' surplus as percentage of average income for the different schemes. From Table 5-6, it can be seen that all the instruments successfully achieve the control target, verifying the traditional axiom in economics literature that the use of prices or quantities as management instruments achieves the same level of efficiency in an idealized environment. Although they achieve the same control target, it can be seen from Table 5-7 that the magnitude of their socioeconomic impacts is variable. Specifically, the flat mileage fee leads to the most adverse percentage change in consumers' surplus as a percentage of income and is regressive, i.e. it affects the lower income groups more adversely than the higher income groups. Conversely, the tradable credit schemes lead to much minor changes and is more progressive i,e its adverse effect increases as income levels increases. This observation is also consistent with the literature where a tradable credit scheme is known to minimize the total cost of reaching a pre-determined environment standard regardless of the initial allocation of credits, provided there is no transaction cost.

Table 5-6. Total Changes in Consumers' Surplus, Revenue and VMT under different Instruments (Deterministic)

Instrument	Total Change Consumer Surplus ($)	Total change in revenue ($)	Total Change in social welfare ($)	% VMT reduction
Gasoline Tax	-2,704,800 (σ=148)	2,283,300(σ=137)	-421,480(σ=16)	15.08
Mileage fee	-4,920,300(σ=316)	3,935,100(σ=267)	-985,250(σ=71)	15.08
Tradable Credits	-478,820(σ=320)	713,740(σ=267)	234,910(σ=413)	15.00

Table 5-7. Average Changes in Consumers' Surplus as Percentage of Average Income

Income group	Gasoline Tax (%)	Mileage Fee (%)	Tradable Credits (%)
$0-$19,999	-0.84	-1.50	1.05
$20,000-$39,999	-0.50	-0.90	0.22
$40,000-$59,999	-0.40	-0.73	-0.04
$60,000-$79,999	-0.35	-0.65	-0.13
$80,000-$200,000	-0.23	-0.42	-0.16

5.2 Comparison of Schemes under Stochastic Travel Demand Function

In the previous section, the household demand function was assumed to be deterministic, however, individual households will respond differently to these policy schemes. This section deals with the situation where there are uncertainties in the individual household travel demand function. Firstly, a comparison of the effectiveness of the three policy schemes in reducing the total VMT by 15% is analyzed. Secondly, the socioeconomic impacts of the three policy schemes are evaluated under such conditions. Below is a typical travel demand function under stochastic degradation following a uniform distribution between the nominal demand used for the analysis:

$$D_1 = (1+\xi)\exp(\beta_o + \beta_1 \times In(EQ) + \beta_2 \times In(hhtinc) + \beta_3 \times In(hhvcnt) + \beta_4 \times U + \beta_5 \times In(hhtinc) \times In(EQ) + \beta_6 \times SUB + \beta_7 \times In(EQ) \times SUB + \beta_8 \times wrkcnt + \beta_9 \times hhchild)$$

where ξ is a uniformly distributed random variable between (-0.15, 0.15).

To achieve this, a Monte Carlo simulation is conducted; different number of samples was tried and one thousand samples were found to be enough for the purpose of this study. Appendix B shows details of the MATLAB program written for the analysis.

5.2.1 Reduction of VMT under Uncertainty

Figure 5-1 shows the results of the percentage reduction in total VMT with number of samples for the three policy schemes. Also shown, are the success rate in achieving 15% reduction of VMT for the three policy schemes. It can be observed that the tradable credit scheme is 100% successful in achieving the desired percent reduction whiles the success rate for the gasoline tax and mileage fee policy schemes are 83.5% and 84.3% respectively.

5.2.2 Price Variation under Uncertainty

In the gasoline tax policy the tax is fixed whiles in the mileage fee policy the mileage fee is fixed. However, as seen in Figure 5-1, under uncertainty, the market clearing price under the tradable credit scheme fluctuates. It was found to range between 1.49cents to 5.97cents; people in the market may not be pleased with such wide variation in the price of credits.

5.2.2 Changes in Socio Economic Indicators under Uncertainty

Figure 5-2 to Figure 5-4 shows the changes in consumers' surplus, revenue and social welfare each for the three policy schemes. Table 5-8 shows a summary of the changes in the socioeconomic indicators under uncertainty. It can be seen from Figure 5-3 that the revenue generated under the tradable credit scheme is constant and for policy and budgeting purposes, the government knows the revenue before the planning year. However for the other two policy schemes i.e. gasoline tax and mileage fee policy, the government will not know the exact revenue in the preceding year when budgeting.

Table 5-8. Total Changes in Consumers' Surplus, Revenue and VMT under different Instruments (Stochastic)

Instrument	Total Change Consumer Surplus ($)	Total change in revenue ($)	Total Change in social welfare ($)	% VMT reduction
Gasoline Tax	-2,886,600	2,428,700	-457,910	15.08
Mileage fee	-4,694,400	3,660,100	-1,034,300	15.08
Tradable Credits	6,868	713,740	720,600	15.00

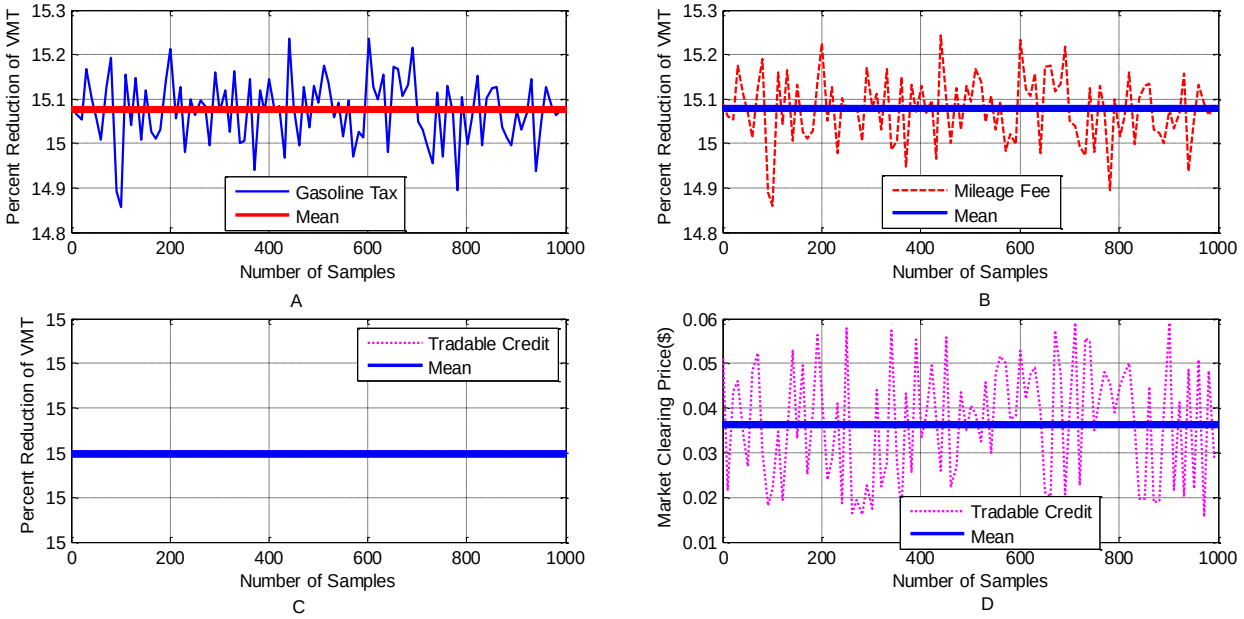

Figure 5-1. Changes in total VMT reduction with number samples for different policies.

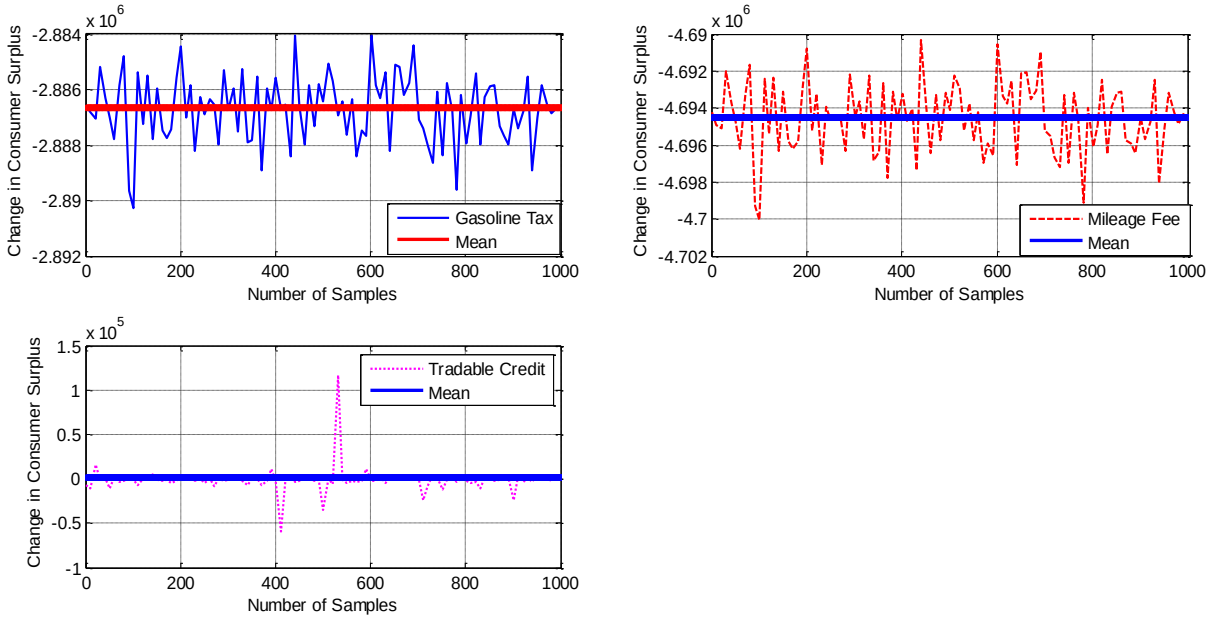

Figure 5-2. Changes in total consumers' surplus with number samples for different policies.

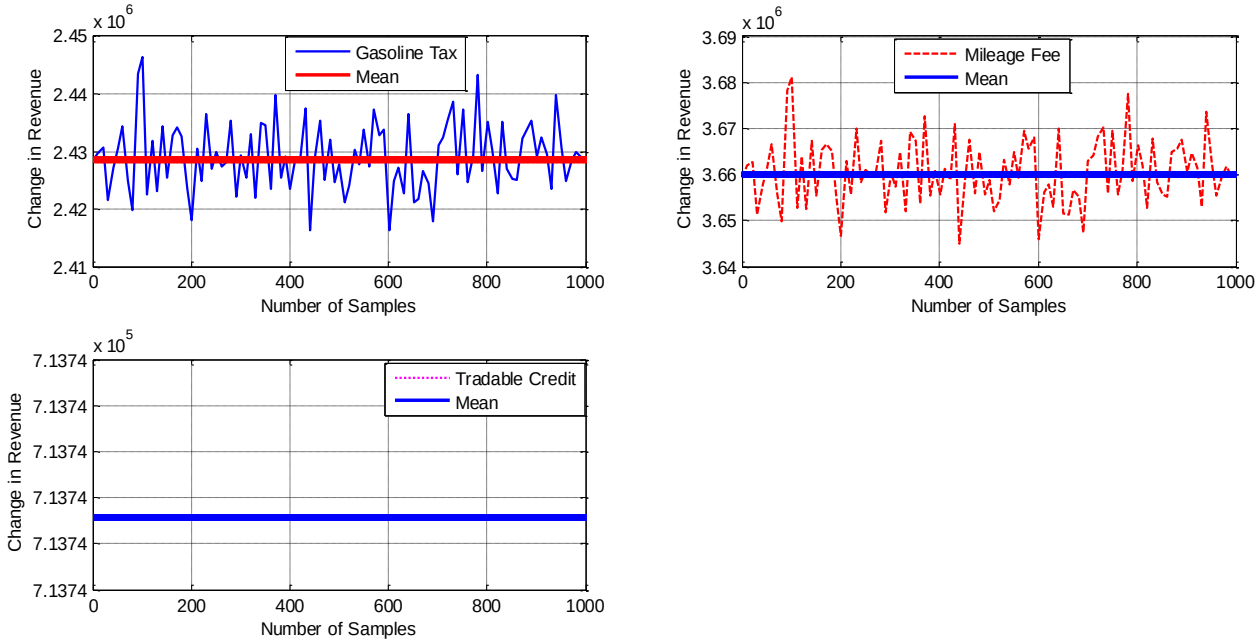

Figure 5-3. Changes in total revenue with number samples for different policies.

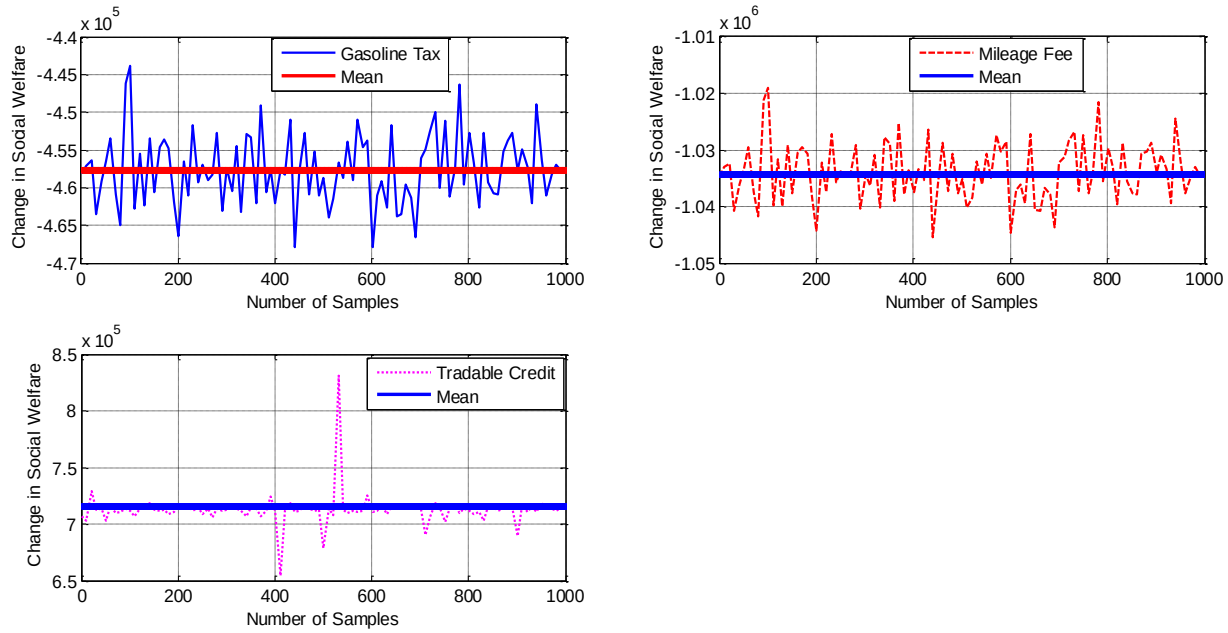

Figure 5-4. Changes in total social welfare with number samples for different policies.

CHAPTER 6
SUMMARY AND CONCLUSIONS

This study compared the socioeconomic impacts of three market-based instruments, gasoline tax, mileage fee and tradable credit schemes, for mobility management. The NHTS 2009 data for was used for the analysis. A hypothetical case study where FDOT intends to reduce the total vehicle miles by 15% in Florida was considered.

Firstly, we developed a deterministic household travel demand function and examined the socioeconomic impact of the three market-based instruments. It was found that the three instruments are capable of achieving the hypothetical 15% reduction of total travel demand in Florida. However, they generate different amounts of revenue and impose different socioeconomic impacts on Florida residents. Gasoline tax and mileage fee schemes charge travelers more to discourage their travels to achieve the control target. Consequently, the government receives much more revenue. At the same time, the schemes hurt residents more and do more harm to the poor than the rich. The tradable credit scheme generates the least revenue for the government but has a less regressive impact on residence.

Secondly, we assumed that the household travel demand function is uncertain and conducted similar analysis to determine the socioeconomic impact of the three instruments. The three policy instruments were all capable of reducing the VMT by 15%. However, the gasoline tax and mileage fee policies were found to have a lower success rate and the revenue generated was variable; this may not be good for the government in terms of budgeting. For the tradable credit, the success rate was found to be 100% and the revenue generated fixed hence helps the government for budgeting purposes. However, we observed price volatility which may not be appealing to people. The socio economic impact was found to be similar to that obtained under the deterministic travel demand.

The comparative analysis does not consider many practical issues such as the implementation and administration costs. A mileage fee scheme is likely to be more costly to implement and operate than the gasoline tax. The implementation cost for a tradable credit scheme is probably the highest among these three instruments. Moreover, the efficiency of the scheme may be adversely affected by transaction costs and speculation behavior in the credit market, which are ignored in our analysis.

The NHTS data do not contain any information on how residents react to a mileage fee or tradable credit policy. Our analysis simply assumed that residents react to them the same way as an increase in gas price, which is not necessarily the case. Moreover, we also assumed that vehicle ownership and land use patterns would remain the same after the implementation of these new instruments. This assumption may be valid for short-term assessment. For a long-term assessment, more advanced models should be used.

APPENDIX A
MATLAB PROGRAM FOR DETERMINISTIC ANALYSIS

```
clear all;
close all;
clc;
data=xlsread('finaldata.xlsx',1,'A2:k13087');
% Assigmnent of variables
hhtotinc=data(:,1);
hhvehcnt=data(:,2);
hhchild=data(:,3);
wrkcnt=data(:,4);
vmt=data(:,5);
rawpm=data(:,6);
sub=data(:,7);
u=data(:,8);
avgprice=data(:,9);
mpg=data(:,10);
net_gas_price=data(:,11);

%creation of new variables initial conditions
gastax=0.345;
vmtfee=0.037; % used for mileage fee calculations
anngallons=vmt./mpg;
gasprice=net_gas_price+gastax;
exp_gas_tax=gasprice.*anngallons;
exp_vmt=net_gas_price.*anngallons+vmt.*vmtfee;
chng_exp=exp_gas_tax-exp_vmt;
pm=rawpm./vmt;
% Regression Parameters
b0=-2.4787;
b1=-5.4067;
b2=0.7612;
b3=0.9188;
b4=-0.1821;
b5=0.3449;
b6=1.6881;
b7=0.7499;
b8=0.1509;
b9=0.1023;

% ELASTICITY BY INCOME

e=b1+b5.*log(hhtotinc)+b7.*sub;  % with sub
e2=b1+b5.*log(hhtotinc);  % without sub

% Calculate a new PM
pm_wotax=(net_gas_price)./(mpg);
pm_tax=(net_gas_price+gastax)./(mpg);
pm_vmt=((net_gas_price)./(mpg)+vmtfee);

% current VMT
tot_vmt=sum(vmt)
% Predicted VMT without gas tax
```

```
lnvmt_wotax=b0 + b1.*log(pm_wotax)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_wotax)+ b6.*sub+b7.*log(pm_wotax).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_wotax=exp(lnvmt_wotax);
totvmt_wottax=sum(vmt_wotax)

%Predicted VMT with gas tax
lnvmt_tax=b0 + b1.*log(pm_tax)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u + b5.*log(hhtotinc).*log(pm_tax)+
b6.*sub+b7.*log(pm_tax).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_tax=exp(lnvmt_tax);

% Detailed Gastax vmt. Omit when necessary

totalvmt_tax=sum(vmt_tax)

%Predicted VMT with mileage fee

lnvmt_fee=b0 + b1.*log(pm_vmt)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmt)+ b6.*sub+b7.*log(pm_vmt).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_fee=exp(lnvmt_fee);


% PREDICTION OF SOCIOECONOMIC PARAMETERS
   % gas tax
gastax1=0.345;
pm_tax1=(net_gas_price+gastax1)./(mpg);

lnvmt_tax1=b0 + b1.*log(pm_tax1)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_tax1)+ b6.*sub+b7.*log(pm_tax1).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_tax1=exp(lnvmt_tax1);

gastax2=0.585;
pm_tax2=(net_gas_price+gastax2)./(mpg);

lnvmt_tax2=b0 + b1.*log(pm_tax2)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_tax2)+ b6.*sub+b7.*log(pm_tax2).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_tax2=exp(lnvmt_tax2);

chng_csg=(pm_tax1-pm_tax2).*(vmt_tax1+vmt_tax2).*0.5;
chng_revg=((gastax2./mpg).*vmt_tax2)-((gastax1./mpg).*vmt_tax1);
chng_swg=chng_csg+chng_revg;

tot_csg=sum(chng_csg)
tot_revg=sum(chng_revg)
tot_swg=sum(chng_swg)
per_chng_vmt_gt=(sum(vmt_tax2)-sum(vmt))/(sum(vmt))
 % Mileage fee
%(note the Pm values used are from the first pm stated)

if vmtfee>0.0164
   chng_csfee=(pm_tax-pm_vmt).*(vmt_tax+vmt_fee).*0.5; % remember to change to difference in PM when the
mileage fee is greater than 1.64(in this case)
else
   chng_csfee=(pm_vmt-pm_tax).*(vmt_tax+vmt_fee).*0.5;
```

```
end

chng_revfee=vmtfee.*vmt_fee-(gastax./mpg).*vmt_tax;
chng_swfee=chng_csfee+chng_revfee;

% Calculation of total Social Economic Parameters (based on mileage fee)
tot_csfee=sum(chng_csfee)
tot_revfee=sum(chng_revfee)
tot_swfee=sum(chng_swfee)

% Changes in VMT
diff_vmt=sum(vmt_tax)-sum(vmt_fee);
per_chng_vmt=diff_vmt*100/sum(vmt_tax)


% IMPLEMENTATION OF TRADABLE CREDITS

   % Total Revenue under current Conditions
   rev_current=(gastax./mpg).*vmt_tax;
   tot_rev_current=sum(rev_current)

% Allocation of credits

   % By household
      curr_vmt=sum(vmt)*0.85; % this is assuming that we intend to reduce the VMT by 15%.
      cred_hh=tot_rev_current/curr_vmt

 % Total Miles credit allocated based on current household
   no_hh=13086;
   mil_credit_hh=(tot_rev_current)/(no_hh*cred_hh)

 % Socio-economic parameter

 % Individual Demand functions
 ind_cred_demand=vmt.*0.85;
 vmtfeem=0.037; %market clearing credit
 pm_vmtm=((net_gas_price)./(mpg)+vmtfeem);
 lnvmt_feen=b0 + b1.*log(pm_vmtm)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmtm)+ b6.*sub+b7.*log(pm_vmtm).*sub + b8.*wrkcnt + b9.*hhchild;
 vmt_feen=exp(lnvmt_feen);

 unit_cred_0=(vmt_tax.*vmtfee- vmt_feen.*0.0161)./(vmt_tax-vmt_feen);

 unit_cred_1=(vmt_tax.*vmtfee- vmt_feen.*cred_hh)./(vmt_tax-vmt_feen);

 chng_demand=mil_credit_hh-vmt_tax;

 chng_cs_cred=0.5*(unit_cred_1+vmtfee).*vmt_feen+chng_demand.*(vmtfee-cred_hh)-
(0.5*unit_cred_0.*vmt_tax);

 rev_cred=vmt.*cred_hh;   % Revenue
```

```
chng_rev_cred=rev_cred-rev_current;

chng_sw_cred=chng_cs_cred+chng_rev_cred;

tot_cs_cred=sum(chng_cs_cred)
tot_rev_cred=sum(chng_rev_cred)
tot_sw_cred=tot_cs_cred+tot_rev_cred
```

APPENDIX B
MATLAB PROGRAM FOR STOCHASTIC ANALYSIS

```
clear all;
close all;
clc;
data=xlsread('finaldata.xlsx',1,'A2:j13087');
% Assigmnent of variables
hhtotinc=data(:,1);
hhvehcnt=data(:,2);
hhchild=data(:,3);
wrkcnt=data(:,4);
vmt=data(:,5);
rawpm=data(:,6);
sub=data(:,7);
u=data(:,8);
avgprice=data(:,9);
mpg=data(:,10);

%creation of new variables
gastax=0.345;
vmtfee=0.037;
anngallons=vmt./mpg;
exp_gas_tax=avgprice.*anngallons;
net_gas_price=avgprice-gastax;
exp_vmt=net_gas_price.*anngallons+vmt.*vmtfee;
chng_exp=exp_gas_tax-exp_vmt;
pm=rawpm./vmt;
% Regression Parameters
b0=-2.4787;
b1=-5.4067;
b2=0.7612;
b3=0.9188;
b4=-0.1821;
b5=0.3449;
b6=1.6881;
b7=0.7499;
b8=0.1509;
b9=0.1023;

% PREDICTION OF SOCIOECONOMIC PARAMETERS
   % gas tax
gastax1=0.345;
pm_tax1=(net_gas_price+gastax1)./(mpg);

lnvmt_tax1=b0 + b1.*log(pm_tax1)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_tax1)+ b6.*sub+b7.*log(pm_tax1).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_tax1=exp(lnvmt_tax1);

gastax2=0.585;
pm_tax2=(net_gas_price+gastax2)./(mpg);

lnvmt_tax2=b0 + b1.*log(pm_tax2)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_tax2)+ b6.*sub+b7.*log(pm_tax2).*sub + b8.*wrkcnt + b9.*hhchild;
```

```
vmt_tax2=exp(lnvmt_tax2);


% Mileage fee

 % Calculate a new PM
pm_wotax=(net_gas_price)./(mpg);
pm_tax=(net_gas_price+gastax)./(mpg);
pm_vmt=((net_gas_price)./(mpg)+vmtfee);

% current VMT
tot_vmt=sum(vmt)

%Predicted VMT with gas tax
lnvmt_tax=b0 + b1.*log(pm_tax)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u + b5.*log(hhtotinc).*log(pm_tax)+
b6.*sub+b7.*log(pm_tax).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_tax=exp(lnvmt_tax);

% Detailed Gastax vmt. Omit when necessary

totalvmt_tax=sum(vmt_tax)

%Predicted VMT with mileage fee

lnvmt_fee=b0 + b1.*log(pm_vmt)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmt)+ b6.*sub+b7.*log(pm_vmt).*sub + b8.*wrkcnt + b9.*hhchild;
vmt_fee=exp(lnvmt_fee);

% IMPLEMENTATION OF TRADABLE CREDITS

   % Total Revenue under current Conditions
   rev_current=(gastax./mpg).*vmt_tax;
   tot_rev_current=sum(rev_current)
    ind_cred_demand=vmt.*0.85;
     vmtfeem=0.037; %market clearing credit
       pm_vmtm=((net_gas_price)./(mpg)+vmtfeem);
       lnvmt_feen=b0 + b1.*log(pm_vmtm)+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmtm)+ b6.*sub+b7.*log(pm_vmtm).*sub + b8.*wrkcnt + b9.*hhchild;
       vmt_feen=exp(lnvmt_feen);
% Allocation of credits

% By household
      curr_vmt=sum(vmt)*0.85; % this is assuming that we intend to reduce the VMT by 15%.
      cred_hh=tot_rev_current/curr_vmt

 % Total Miles credit allocated based on current household
   no_hh=13086;
   mil_credit_hh=(tot_rev_current)/(no_hh*cred_hh);

 % Socio-economic parameter

 % Individual Demand functions
 ind_cred_demand=vmt.*0.85;
```

```
N=1000;

%for z=1:2
%for j=1:10
    for i=1:N
      r(:,i)=-0.15+0.3*rand(1,13086);    % Generate random numbers
      r(:,i)=reshape(r(:,i),13086,1);        % this converts it into a column vector

      vmt_taxn(:,i)=(1+r(:,i)).*exp(lnvmt_tax2);
      sumvmt_taxn(:,i)=sum(vmt_taxn(:,i));   % VMT Gas Tax

      vmt_feem(:,i)=(1+r(:,i)).*exp(lnvmt_fee);
      sumvmt_feem1(:,i)=sum(vmt_feem(:,i));    % VMT Mileage fee

      vmt_feen(:,i)=(1+r(:,i)).*exp(lnvmt_feen);
      sumvmt_feen(:,i)=sum(vmt_feen(:,i));

      % Changes in socioeconomic measures
      chng_csg(:,i)=(pm_tax1-pm_tax2).*(sum(vmt_tax1)+sumvmt_taxn(:,i)).*0.5;
      chng_revg(:,i)=((gastax2./mpg).*sumvmt_taxn(:,i))-((gastax1./mpg).*sum(vmt_tax1));
      chng_swg(:,i)=chng_csg(:,i)+chng_revg(:,i);

      tot_csg(:,i)=mean(chng_csg(:,i));
      tot_revg(:,i)=mean(chng_revg(:,i));
      tot_swg(:,i)=mean(chng_swg(:,i));

      % Changes in VMT
      per_chng_vmt_gt(:,i)=abs(((sumvmt_taxn(:,i))- sum(vmt))*100/(sum(vmt)));

      % mileage Fee
       % Mileage Fee

   if vmtfee>0.0164
  chng_cs_fee(:,i)=(pm_tax-pm_vmt).*(sum(vmt_tax)+sumvmt_feem1(i)).*0.5;
   else
  chng_cs_fee(:,i)=(pm_vmt-pm_tax).*(sum(vmt_tax)+sumvmt_feem1(i)).*0.5;

   end

  chng_rev_fee(:,i)=vmtfee.*sumvmt_feem1(i)-(gastax./mpg).*sum(vmt_tax);
  chng_sw_fee(:,i)=chng_cs_fee(:,i)+chng_rev_fee(:,i);

  % Calculation of total Social Economic Parameters (based on mileage fee)
  tot_cs_fee(:,i)=mean(chng_cs_fee(:,i));
  tot_rev_fee(:,i)=mean(chng_rev_fee(:,i));
  tot_sw_fee(:,i)=mean(chng_sw_fee(:,i));
   % Changes in VMT
   per_chng_vmtfee(:,i)=abs(((sumvmt_feem1(:,i))- sum(vmt_tax))*100/(sum(vmt_tax)));

 % Bisection Method

      vmtfee1(i)=0.01;                        % start of interval
```

```
    vmtfee2(i)=0.080;                    % end of interval
    n=1000;
    pm_vmt1(:,i)=((net_gas_price)./(mpg)+vmtfee1(:,i));
    lnvmt_fee1(:,i)=b0 + b1.*log(pm_vmt1(:,i))+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmt1(:,i))+ b6.*sub+b7.*log(pm_vmt1(:,i)).*sub + b8.*wrkcnt + b9.*hhchild;
    %vmt_fee1(i)=exp(lnvmt_fee1(i));
    vmt_fee1(:,i)=(1+r(i)).*exp(lnvmt_fee1(:,i));
    sumvmt_fee1(:,i)=sum(vmt_fee1(:,i));
     % Changes in VMT
    diff_vmt1(i)=sum(vmt_fee1(:,i))-sum(vmt_tax);
    f_a(i)=(diff_vmt1(i)*100/sum(vmt_tax))+15;

    pm_vmt2(:,i)=((net_gas_price)./(mpg)+vmtfee2(:,i));
    lnvmt_fee2(:,i)=b0 + b1.*log(pm_vmt2(:,i))+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmt2(:,i))+ b6.*sub+b7.*log(pm_vmt2(:,i)).*sub + b8.*wrkcnt + b9.*hhchild;
    %vmt_fee2=exp(lnvmt_fee2);
    vmt_fee2(:,i)=(1+r(i)).*exp(lnvmt_fee2(:,i));
    sumvmt_fee2(i)=sum(vmt_fee2(:,i));
    % Changes in VMT
    diff_vmt2(i)=sum(vmt_fee2(:,i))-sum(vmt_tax);
    f_b(i)=(diff_vmt2(i)*100/sum(vmt_tax))+15;

  if f_a(i)*f_b(i)> 0.0
       error ('same end points.')
  end

    for j = 1:n

    c(i)=(vmtfee2(i)+vmtfee1(i))/2;

    pm_vmtc(:,i)=((net_gas_price)./(mpg)+c(:,i));
    lnvmt_feec(:,i)=b0 + b1.*log(pm_vmtc(:,i))+ b2.*log(hhtotinc)+ b3.*log(hhvehcnt)+ b4.*u +
b5.*log(hhtotinc).*log(pm_vmtc(:,i))+ b6.*sub+b7.*log(pm_vmtc(:,i)).*sub + b8.*wrkcnt + b9.*hhchild;
    %vmt_fee2=exp(lnvmt_fee2);
    vmt_feec(:,i)=(1+r(i)).*exp(lnvmt_feec(:,i));
    sumvmt_feec(i)=sum(vmt_feec(:,i));
    % Changes in VMT
    diff_vmtc(i)=sum(vmt_feec(:,i))-sum(vmt_tax);
    f_c(i)=(diff_vmtc(i)*100/sum(vmt_tax))+15;
     %disp([    c     f_c])
    if f_c(i) == 0.0     % solved the equation exactly
    e = 0.0001;
    break      % jumps out of the for loop
    end
     if c(i)*f_c(i) < 0
    vmtfee2(i)=c(i);
    else
    vmtfee1(i)=c(i);
     end
    end
       e(i) = (vmtfee2(i)-vmtfee1(i))/2;
       c(i);

   fee(i)=c(i);
```

```
    % Tradable credits
  % VMT tradable credits

   unit_cred_0(:,i)=((vmt_tax).*fee(i)- (vmt_feen(i)).*0.0161)./((vmt_tax)-(vmt_feen(:,i)));

   unit_cred_1(:,i)=((vmt_tax).*fee(i)- (vmt_feen(:,i)).*cred_hh)./((vmt_tax)-(vmt_feen(:,i)));

   chng_demand=mil_credit_hh-vmt_tax;

   chng_cs_cred(:,i)=0.5.*(unit_cred_1(:,i))+fee(i).*vmt_feen(:,i)+chng_demand.*(fee(i)-cred_hh)-
(0.5.*unit_cred_0(:,i).*(vmt_tax));

   rev_cred=vmt.*cred_hh;   % Revenue

   chng_rev_cred=rev_cred-rev_current;

   chng_sw_cred(:,i)=chng_cs_cred(:,i)+chng_rev_cred;


  % Tradable
   tot_cs_cred(:,i)=mean(chng_cs_cred(:,i));
   tot_rev_cred(i)=sum(chng_rev_cred);
   tot_sw_cred(:,i)=tot_cs_cred(:,i)+tot_rev_cred(i);

   per_chng_vmt_cred(:,i)=abs(((sumvmt_feec(:,i))- sum(vmt_tax))*100/(sum(vmt_tax)));

    end

    x=1:10:1000;
    z=1:1:1000;
    %Means
    %Percentage Changes
    mean(per_chng_vmt_gt)
    mean(per_chng_vmtfee)
    mean(per_chng_vmt_cred)
    % Changes in Consumer surplus
    mean(tot_csg)
    mean(tot_cs_fee)
    mean(tot_cs_cred)
    % Changes in Revenue
    mean(tot_revg)
    mean(tot_rev_fee)
    mean(tot_rev_cred)

    % Changes in social welfare
    mean(tot_swg(x))
    mean(tot_sw_fee)
    mean(tot_sw_cred)

    % Ploting Percentage Reduction in VMT
      figure
      subplot(221);plot(x,per_chng_vmt_gt(x),'b','LineWidth',1.5);
```

```
hold on
plot(z,mean(per_chng_vmt_gt),'r','LineWidth',2);
xlabel('Number of Samples');
ylabel('Percent Reduction of VMT');
legend('Gasoline Tax','Mean');
grid on;

hold on
subplot(222);plot(x,per_chng_vmtfee(x),'--r','LineWidth',1.5);
hold on
plot(z,mean(per_chng_vmtfee),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Percent Reduction of VMT');
legend('Mileage Fee','Mean');
grid on;

hold on
subplot(223);plot(x,per_chng_vmt_cred(x),':m','LineWidth',1.5);
hold on
plot(z,mean(per_chng_vmt_cred),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Percent Reduction of VMT');
legend('Tradable Credit','Mean');
grid on;
hold off

hold on
subplot(224);plot(x,c(x),':m','LineWidth',1.5);
hold on
plot(z,mean(c),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Market Clearing Price($)');
legend('Tradable Credit','Mean');
grid on;
hold off

% Plotting  Changes in Consumer Surplus
figure
subplot(221);plot(x,tot_csg(x),'b','LineWidth',1.5);
hold on
plot(z,mean(tot_csg),'r','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Consumer Surplus');
legend('Gasoline Tax','Mean');
grid on;

hold on
subplot(222);plot(x,tot_cs_fee(x),'--r','LineWidth',1.5);
hold on
plot(z,mean(tot_cs_fee),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Consumer Surplus');
legend('Mileage Fee','Mean');
grid on;
```

```
hold on
subplot(223);plot(x,tot_cs_cred(x),':m','LineWidth',1.5);
hold on
plot(z,mean(tot_cs_cred),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Consumer Surplus');
legend('Tradable Credit','Mean');
grid on;
hold off

% Plotting  Changes in Revenue

figure
subplot(221);plot(x,tot_revg(x),'b','LineWidth',1.5);
hold on
plot(z,mean(tot_revg),'r','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Revenue');
legend('Gasoline Tax','Mean');
grid on;

hold on
subplot(222);plot(x,tot_rev_fee(x),'--r','LineWidth',1.5);
hold on
plot(z,mean(tot_rev_fee),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Revenue');
legend('Mileage Fee','Mean');
grid on;

hold on
subplot(223);plot(x,tot_rev_cred(x),':m','LineWidth',1.5);
hold on
plot(z,mean(tot_rev_cred),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Revenue');
legend('Tradable Credit','Mean');
grid on;
hold off

% Plotting  Changes in Social Welfare

figure
subplot(221);plot(x,tot_swg(x),'b','LineWidth',1.5);
hold on
plot(z,mean(tot_swg(x)),'r','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Social Welfare');
legend('Gasoline Tax','Mean');
grid on;

hold on
subplot(222);plot(x,tot_sw_fee(x),'--r','LineWidth',1.5);
hold on
```

```
plot(z,mean(tot_sw_fee),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Social Welfare');
legend('Mileage Fee','Mean');
grid on;

hold on
subplot(223);plot(x,tot_sw_cred(x),':m','LineWidth',1.5);
hold on
plot(z,mean(tot_sw_cred),'b','LineWidth',2);
xlabel('Number of Samples');
ylabel('Change in Social Welfare');
legend('Tradable Credit','Mean');
grid on;
hold off
```

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BIOGRAPHICAL SKETCH

Patrick Amoah Bekoe was born in 1979 at Koforidua, Ghana. He attended the Kwame Nkrumah University of Science and Technology from September 1998 to June 2002 where he earned his Bachelor of Science degree in civil engineering in March 2003. From August 2002 to July 2003, he undertook his Ghana national service with YAB Engineering Services, a private civil engineering firm located at Tema, Ghana. He was employed with the Department of Feeder Roads under the Ministry of Roads and Highway from October 2003 and awarded the Ministry of Transportation Fellowship to pursue his master's degree in civil engineering at the University of Florida in January 2008. He graduated with a Master of Engineering in civil engineering from the University of Florida in August 2009 and continued subsequently to pursue a PhD in the same field after he was awarded the graduate school fellowship by the University of Florida. In spring 2010, he was officially admitted to the Department of Economics to pursue a Master of Arts in economics; his specialization was in transportation economics. He graduated with a Master of Arts in economics and Doctor of Philosophy in civil engineering in spring 2013. Patrick Amoah Bekoe will be taking a faculty position at the Higher Colleges of Technology in the United Arab Emirates before returning to Ghana to work for the Ministry of Roads and Highway.