A Framework for Determining Road Pricing Revenue Use and Its Welfare Effects

Timothy F. Welch[a], Sabyasachee Mishra[b*]

[a] School of City and Regional Planning, Georgia Institute of Technology, Atlanta, GA 30332, United States

[b] Department of Civil Engineering, University of Memphis, Memphis, TN 38152, United States

Abstract

In the last five decades, much of the focus on travel cost has been on what form pricing should take, whether it should be a direct road toll, in the form a Vehicle Miles Traveled (VMT) tax, encapsulated in the gas tax, or by some other mechanism. An area that has received much less attention, but is nonetheless important when considering any pricing change, is the impact of such mechanisms on traveler welfare and travel time savings. While an increase in the cost of travel may achieve traffic flow efficiencies, it may also unduly burden low-income travelers or unjustly benefit higher-income drivers. An important aspect of the road pricing debate is not just whether pricing will produce an efficient market, but also if such pricing is implemented, how the generated revenue will be managed. We propose a model to analyze transport equity by measuring change in traveler welfare and travel time savings as a result of a mix of road pricing, revenue recycling (tax cuts) and transit subsidies. In this paper we introduce a multimodal travel demand model to incorporate road-pricing mechanisms with various subsidy options. A Base Case and five scenarios are developed to address various hypothetical pricing scenarios. We find the structure of the road pricing mechanism on average has a small impact on annual per capita traveler welfare. Replacing the state gas tax with a VMT tax can have a positive impact on traveler welfare, particularly for lower-income groups and rural residents. A VMT tax increase would be the least detrimental to welfare, especially for low-income groups.

Keywords: pricing, VMT tax, welfare, travel time savings, travel demand model

---

*Corresponding author.: Tel.: +1 901 678 5043, fax.: +1 901 678 3026

E-mail address: tim.welch@coa,gatech.edu (Timothy F. Welch), smishra3@memphis.edu (Sabyasachee Mishra)

1. Introduction

The primary source for interstate funding in the United States is the Highway Trust Fund (HTF). However, the HTF has been nearly insolvent since 2008, surviving primarily on cash transfers from the general fund with the possibility of facing real insolvency in the near term future. The dwindling cash flow to the HTF is the result of several factors. Most notable is the stagnant level of federal gas tax, which has not kept pace with inflation. The federal gas tax has not increased in 20 years. The HTF has also been paralyzed by congressional inaction and further eroded by market driven increases to average fleet fuel economy and is threatened by rapidly approaching increases in Corporate Average Fuel Economy (CAFE) standards, which may significantly increase fuel efficiency.

To address the coming financial quagmire scholars have proposed either replacing or supplementing the gas tax with some form of per-mile road pricing scheme (Arnott, Palma, & Lindsey, 1994; Eliasson & Mattsson, 2006; Franklin, 2007; Fridstrøm, Minken, Moilanen, Shepherd, & Vold, 2000; Small, 1992). The most commonly cited mileage-based pricing strategy is pay-as-you-drive (PAYD) insurance. Studies have found that PAYD leads to a commonly desirable outcome of reduced VMT (Glaister and Graham 2005; Parry, 2005; Abou-Zeid, Ben-Akiva, Tierney, Buckeye, & Buxbaum, 2008; Bordoff & Noel, 2008). Related to this pricing mechanism is an increasingly more feasible vehicle miles traveled (VMT) tax, which would track individual traveler mileage and charge users accordingly (Greene, 2011). Such a tax has been viewed as an attractive alternative to the fuel tax for many reasons (Parry and Small, 2005). However it has not been a viable alternative to the gas tax until recently when the technology to implement such a tax has been commercially available and affordable at a large scale (Fuetsch, 2009; Kim, Porter, & Wurl, 2002). With available technology, a VMT tax has been a genuinely considered policy option in many states, with pilot programs in Minnesota, New York, Oregon and more widely across Europe (NYSDOT Task Assignment, 2012; Smalkoski & Levinson, 2005; Sorensen & Taylor, 2005; Starr McMullen, Zhang, & Nakahara, 2010; Zhang & McMullen, 2008).

While a VMT tax offers a way to avoid the looming decline in revenue brought on by increases in fuel efficiency, advocates and opponents of a VMT tax typically are split around the distributional aspects of the tax. Changes in travel cost have significant impacts on different income groups depending on (a) the type of change in travel cost and (b) the magnitude of the change. Proponents of the tax argue that it is a much more equitable form of user fee than a fuel tax (Ecola & Light, 2009; Forkenbrock, 2005). Such a per-mile fee may be less of a burden to lower-income travelers who may have lower efficiency vehicles. Even where there is evidence that there are equity issues with a transition to a VMT-type fee, the literature generally confirms that those issues can be resolved (Levinson, 2010). Another major distributional argument is whether a VMT tax is better at charging users for their actual consumption of the good (road space, congestion, road maintenance cost) versus the more traditional gas tax. Tangent to this argument is the concern that a mileage-based fee may have an adverse impact on drivers that must travel more miles because of the location of their residence or place of employment, particularly those in rural locations. Each of these factors variably influence traveler welfare and travel time savings, two key measures of distributional impacts. A number of studies have estimated changes in welfare from a tax increase or the implementation of a VMT tax in place of some portion of the gas tax. This is typically done with regression using the National Household Travel Survey (NHTS) or similar data sources (Cervero & Hansen, 2002). While these studies provide important insights into potential distributional implications, they are limited by the aggregate nature of the NHTS and do not capture important behavioral aspects of travel. We aim to examine each of these arguments using a large-scale transportation demand model for the state of Maryland.

2. Background

While research on road pricing has a long history, from the initial arguments by Pigou (1920) and Knight (1924) to its more thorough formulations by Walters (1961), Mohring and Harwitz (1962) and Vickery (1963); in the last five decades, much of the focus has been on finding optimal pricing to ensure an efficient market. That is, formulating a pricing scheme that charges users for the externalities they cause. A considerable debate has also been over the form of such pricing; whether it should be a direct road toll, a Vehicle Miles Traveled (VMT) tax, encapsulated in the gas tax, or by some other mechanism (Welch & Mishra, *Forthcoming*). The approach in the US since 1932 has been to charge most users through a gas tax.

Conceptually, the gas tax differs from road pricing (e.g. a VMT tax) in three ways. First, the amount of gas consumed and thus the amount of taxes paid varies depending on the type of vehicle a road user drives. Some drivers have a greater level of control over total travel cost than others. The costs can be reduced by changing modes, driving shorter distances or, for those with enough income, purchasing a more fuel-efficient vehicle. Road pricing, especially in the form of a VMT tax leaves drivers with fewer cost reduction options. On the other hand, many policy makers favor road pricing because its revenue is not affected by changes in vehicle efficiency. The second way a gas tax differs from mileage-based road pricing is that a gas tax is charged upfront (before a trip is taken) and generally hidden within the price of fuel, so users are less likely to link driving behavior to added fuel cost (Li et al., 2012). This hidden price can reduce the effect a gas tax has on travel behavior. The gas tax provides an advantage over some prior road pricing implementations in requiring advanced payment that will not reduce the flow of traffic as part of the collection process. However, this difference is being reduced by changes in technology that simplify the road charges (e.g. electronic tolling) that may also obscure the direct link between travel and cost. Third, while drivers do not closely link gas taxes to travel behavior like trip timing and route selection, studies have shown that drivers typically have higher consumption elasticity for gas prices than for road charges, likely because of a difference in substitution options (Parry and Small, 2005).

The advantage of a VMT-based tax is to encourage travelers to use transit as an alternate mode if the VMT tax increases the cost of personal vehicle travel above the general cost of transit. The VMT based tax is associated with traveler value of time (VOT). Users with a low VOT may consider using transit as an alternative mode as the apparent cost of travel increases. From an implementation point of view, fees could be collected annually through a vehicle registration process, as mileage calculated through odometer readings, using on-board GPS or even through smart phone apps (Bertini & Rufolo, 2004; Kim et al., 2008).

An area that has received less attention, but is nonetheless important when considering any pricing change, is the impact of such mechanisms on traveler welfare and travel time savings. While an increase in the cost of travel may achieve a Pareto optimal result for flow efficiency (Button, 1995), it may also unduly burden low-income travelers or unjustly benefit higher income drivers (Levinson, 2010). Thus an important aspect of the road pricing debate is not just whether pricing will produce and efficient market, but if such pricing is implemented, how will the change impact different groups and how the generated revenue will be managed (Peters & Kramer, 2012; Santos & Rojey, 2004).

There are a number of studies that find a positive impact from changes in road pricing policies or measure the distributional impacts of road pricing, specifically the effect of moving from a gas tax to a VMT tax (Glaister & Graham, 2005). Weatherford (2011) studied the impact of moving to a VMT tax on various groups including several income classes, rural and urban travelers and drivers by life stage (i.e. household with children, retired). The results of the analysis found that low-income, rural and retired households could see positive distributional effects. Zhang et al. (2009) studied the distributional impact of a 1.2 cent per mile VMT tax in Oregon and found a very small undesirable impact; concluding that the effects were so small that they should not be considered in a policy decision.

Another important consideration with any proposed road pricing change is how revenue will be used. One contentious potential use of road pricing revenue is to subsidize public transit (Small, 1992). Another less conventional use of revenue is to use the proceeds from road pricing to offset another tax. Several past studies from a broad range of disciplines have found that welfare can be significantly enhanced with revenue recycling schemes (Felder & van Nieuwkoop, 1996; Parry and Bento, 2001; Shackleton et al., 1992; Strand, 1998).

The rest of this paper proceeds as follows. Section three describes the methodology employed by the study, including an in-depth discussion of the behavior model and the scenario construction. Section four offers a description of the study and the data used to conduct the analysis. Section five provides results, followed by section six which offers a discussion of the findings and conclusions.

3. Methodology

We propose a model to analyze changes of equity implications in road pricing policies, measured through traveler welfare and travel time savings as a result of a set of scenarios with road pricing, revenue recycling (tax cuts) and transit subsidies. In the first scenario, we introduce a simple, per-mile VMT tax to replace the Maryland state gas tax. A second and third scenarios analyzes the effects of a tax increase, first implemented as a gas tax then as a VMT tax. The fourth, and fifth scenarios examine the impact of different uses of the proposed VMT tax revenue by either recycling the revenue by lowering the gas tax for all drivers or by subsidizing transit fares. We measure changes in traveler welfare (consumer surplus) and the travel time savings effects of the proposed road pricing scenarios compared to a baseline with no additional pricing to determine which policy produces the best outcome on both metrics.

This paper examines the welfare and travel time savings effects of road pricing, primarily by replacing the Maryland state gas tax with a VMT tax. While there are many complications involved with switching tax schemes such as determining an optimal toll price (Verhoef, 2002), impacts of the scheme on network performance (May & Milne, 2000) or the cost of implementing and administering the policy (Balducci, 2011), we focus on the direct effects on travelers. To accomplish this we use a travel demand model that follows a traditional four-step approach. Figure 1 shows the general flow, inputs and parameters that function to simulate traveler response to several road pricing scenarios.

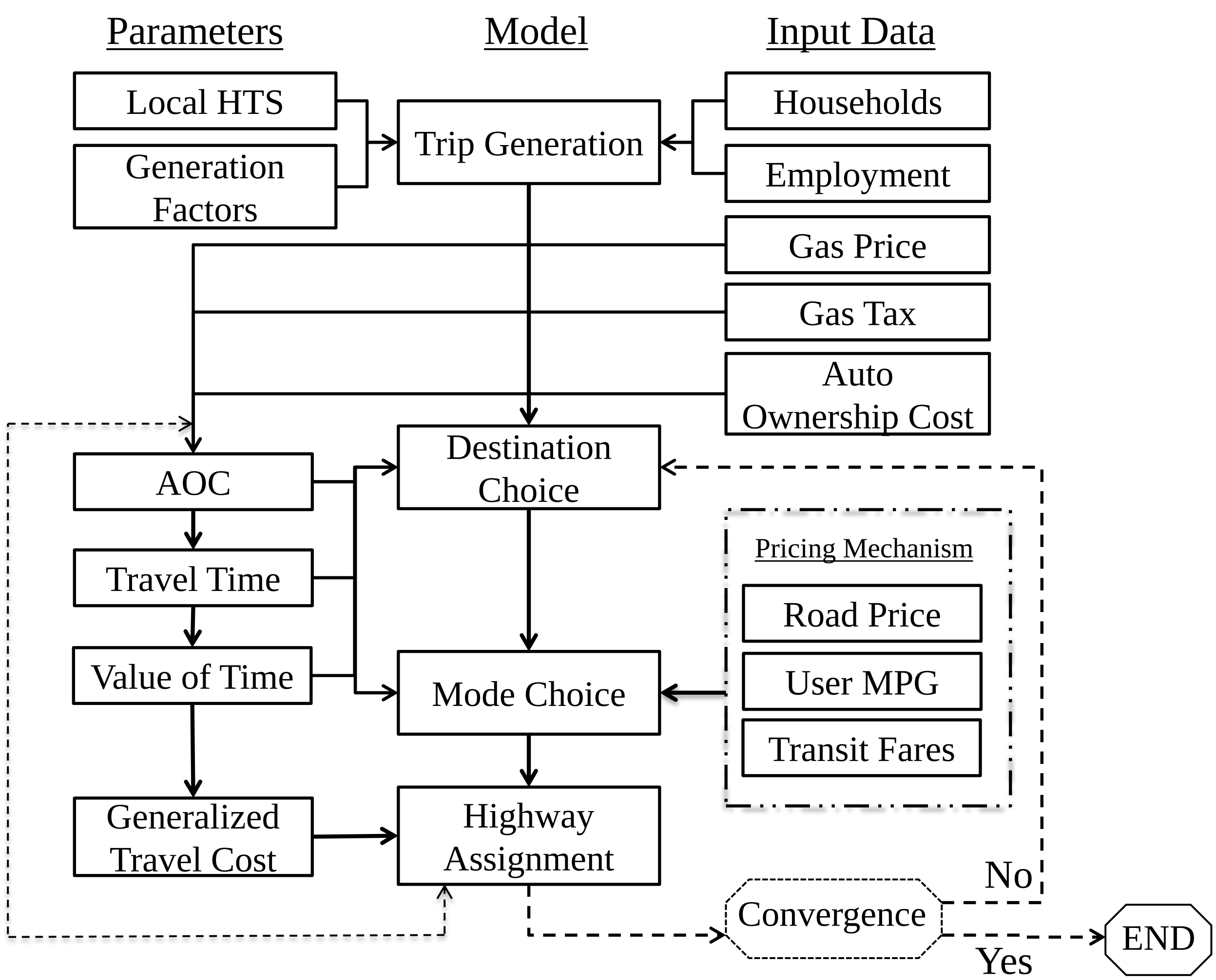


Figure 1. Model Flow Diagram

The model also represents an enhancement over common recursive models by 1) using a destination choice model rather than the traditional trip distribution step, 2) incorporating average fuel efficiency of road users based on income and 3) implementing a feedback loop (that runs iteratively until a relative gap of 0.001 is achieved) to simulate travelers' destination and modal response to congested highway conditions.

Several layers of empirical data help to better simulate the study area's real conditions. We incorporate a full range of travel costs including local gas prices, state and federal gas taxes and non-gas related travel costs (e.g. toll). Further, road pricing, user miles per gallon (MPG) and transit fares are used to capture the full cost of travel. Travel time for auto travelers and in-vehicle and out of vehicle travel time for transit riders are included and scaled by the individual passenger's value of time (VOT). The scenarios constructed for analysis are presented below, summarized in Table 1 and their mathematical formulation is presented in the Appendix.

Table 1: Scenario Summary

Scenario	Scenario Terminology	User Payments	Unit
Secnario-0	Base case		
Secnario-1	Replace Gas Tax w/VMT-based Tax	1.02	Cents/mile
Secnario-2	Simple Gas Tax Increase	11.23	Cents
Secnario-3	Simple VMT Tax Increase	1.5	Cents/mile
Secnario-4	VMT Tax Revenue Recycling	0.30	Cents/mile
Secnario-5	VMT Tax Transit Subsidy	0.80*fare	$/trip

3.1 Base-case

The traffic flow across the study area network is determined by solving a user equilibrium traffic assignment problem. The fundamental aim of the traffic assignment process is to reproduce in a behavioral model, the transportation system represented by the pattern of vehicular and personal trips that would be observed in the real world. The traffic assignment model is based on the principle of user equilibrium and solved by Frank Wolfe algorithm. This principle is based on the fact that individuals choose a route in order to minimize their travel time or travel cost and such a behavior on the individual level creates equilibrium at the system (or network) level over a long period of time (Sheffi 1984). The base year analyzed in the paper is 2007 and the subsequent results are also for the year 2007.

3.2 Scenario-1: Effects of replacing the gas tax with a VMT Tax

There are two subsets to the first scenario in which we simulate the effect of replacing the Maryland gas tax with a VMT tax. The first sub scenario provides the baseline from which equity impacts and travel time savings will be measured. The second scenario implements a VMT tax in place of the current state gas tax.

3.2.1 Gas Tax

The effect of gas price on user behavior consists of the gas price in dollars per mile (as a ratio of dollars per gallon and income stratified vehicle efficiency) and other variables such as the distance each driver travels, the cost of existing road tolls and VOT. Auto Operating Cost (AOC) is another component, which is considered in the mode and destination choice sections of the model. The source and use fuel efficiency data in this paper is explained in greater detail in section 4.

3.2.2 VMT Tax

An alternative pricing method to the traditional gas tax is to impose fees based on the number of miles driven on roadways or a vehicle miles traveled (VMT) based tax. In this scenario we completely replace the Maryland gas tax and with an equivalent VMT tax. In this case, the VMT tax is indexed to the state gas tax and an average fleet efficiency of 23.69 MPG, derived from the NHTS 2009. This results in replacing the entire state gas tax with a 1.02 cent per mile tax.

3.3. Scenario-2: Effects of increasing tax

A second test of the different distributional effects associated with the two forms of tax is developed in this analysis. In the first scenario an increase to the Maryland state gas tax is modeled. In the second scenario the tax increase is applied to the proposed VMT tax.

3.3.1. Increasing the Gas tax

The travel model use for this research is calibrated for the year 2007. In this year the state portion of the Maryland gas tax was 23.5 cents per gallon of retail gasoline, a rate that had not changed since 1992 ("Md. gas tax," n.d.).[1] If the tax were to have been indexed to the rate of inflation (using the standard CPI) the tax rate would have increased by 11.23 cents by the year 2007 (the scenario base year for this model) to 34.73 cents. We adjust the model to reflect this price, implementing a new gas tax across the entire state of Maryland.

3.3.2 Increasing the VMT tax

The proposed VMT tax, as previously discussed, is indexed to the Maryland gas tax. Matching the inflation-index change to the gas tax, an increase of 11.23 cents per gallon translates to an additional VMT tax of .48 cents per mile assuming a fleet wide average fuel efficiency of 23.69 mpg. The total VMT tax in this scenario is thus increased to 1.5 cents per mile.

3.4. Scenario-3: VMT tax revenue use

The primarily concern of this paper is how a switch to a VMT tax affects traveler welfare and travel time savings. The ways in which such a pricing scheme can substantially affect these metrics is through different uses of the generated revenue. The current gas tax is used primarily for highway maintenance and expansion and some transit investments. While this revenue use does benefit travelers, we contemplate ways the revenue can be used for direct subsidization to more efficiently benefit travelers with the following scenarios.

3.5. Scenario-4: Revenue recycling to reduce fuel tax

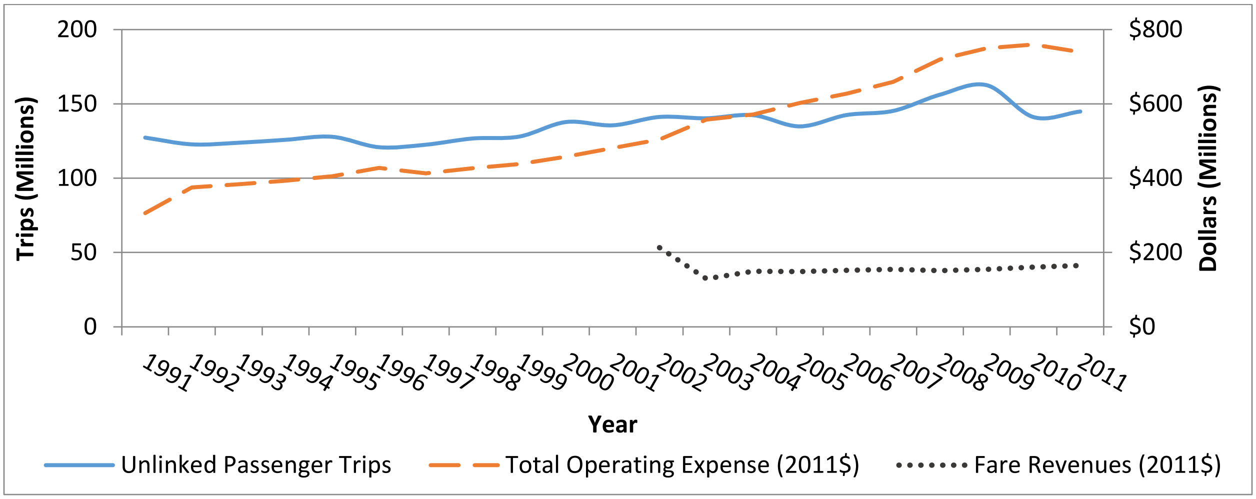
Revenue recycling involves using a portion of revenues from one taxing mechanism to offset another tax. In this paper we propose using an added state VMT tax (indexed at 11.23 cents per gallon) to reduce the equivalent amount of federal gas tax. Thus the federal gas tax portion of AOC is reduced to just 7.2 cents per gallon or an average of .30 cents per mile. Doing so will raise revenue generated over time above the required federal tax. This novel approach has equity implications for travelers that will be examined in this scenario.

3.6. Scenario-5: Subsidy for transit fares

One commonly debated use of revenue from road pricing is to subsidize the cost of public transit. In Maryland each transit trip is already heavily subsidized with a cost per unlinked passenger trip

[1] On July 1, 2013 Maryland increased its gas tax by 3.5 cents per gallon, the first increase since 1992.

of nearly $5.10, while fare box recovery (the ratio of fare revenue to total expenses) is just 22 percent (Figure 2).



Source: NTD, TS2 - Operating Expenses, Service Supplied and Consumed Dataset (NTD, 2011)
Figure 2. Unlinked transit trips, fare revenues, and total transit expenditures, 1991 – 2011

While the cost of a transit trip is significantly subsidized, it can still pose a burden for many low-income groups. Added to the fare expense, is the amount of time an individual must wait for a vehicle to arrive, wait for a transfer and walk from a bus stop to the passenger's ultimate destination. This out-of-vehicle wait time when added to the monetary expense of a transit trip has a significant detrimental effect when travelers (especially choice transit riders) are selecting a mode. To explore the effect of using revenue generated from road pricing to further subsidize transit, we analyze a scenario that reduces all transit fares in the state of Maryland by 20 percent.

3.7. Measuring Distributional Changes

3.7.1. Traveler Welfare

Traveler welfare as measured in this study is the consumer surplus derived from individual route choice decisions; influenced by changes in travel cost. Using the classic rule of half formulation, the total travel cost savings for five income classes of users (based on each classes' VOT, Table 2) is multiplied by the original travel demand and added to half the travel time multiplied by the new travel demand for a path between an origin and destination after a particular policy is applied. The formulation of traveler welfare using the rule of half is presented in the Appendix.

3.7.2. Value of Travel Time Variability

A second important measure of a transport policy's impact on travelers is the monetized value of travel time variance (TTV). The TTV formulation is presented in the Appendix. Variability is measured as a function of the congested travel time on a link multiplied by the variance in contested travel time on the same link between the Base Case model results and a new scenario model result. The measure is then summed for all path constituent links for all drivers, across the entire network. This method has been applied in Atlanta, Los Angeles, Seattle and Minneapolis (Kockelman, Fagnant, Nichols, & Boyles, 2012; Margiotta et al., 2013). The level of change (or variability) in link travel time has a significant impact on traveller welfare as reductions in travel time provide travellers the opportunity to spend more time engaged in other activities or to travel to more destinations with the same travel time budget (K. Button, 2004; Raux, Souche, & Pons, 2012; Safirova et al., 2004). Travel time savings is monetized based on each traveler's value of time, which is used to approximate the traveler value of travel time savings ((Black & Fearon, 2009; Horowitz & Granato, 2012).

4. Case Study and Data

To measure the effect of these strategies several models are constructed at various base resolutions, but all are aggregated and reported at a meso-scopic level. This meso level was achieved by dividing the state into 1,151 zones, called Statewide Modeling Zones (SMZs). Figure 3 shows the SMZ structure for the entire state.

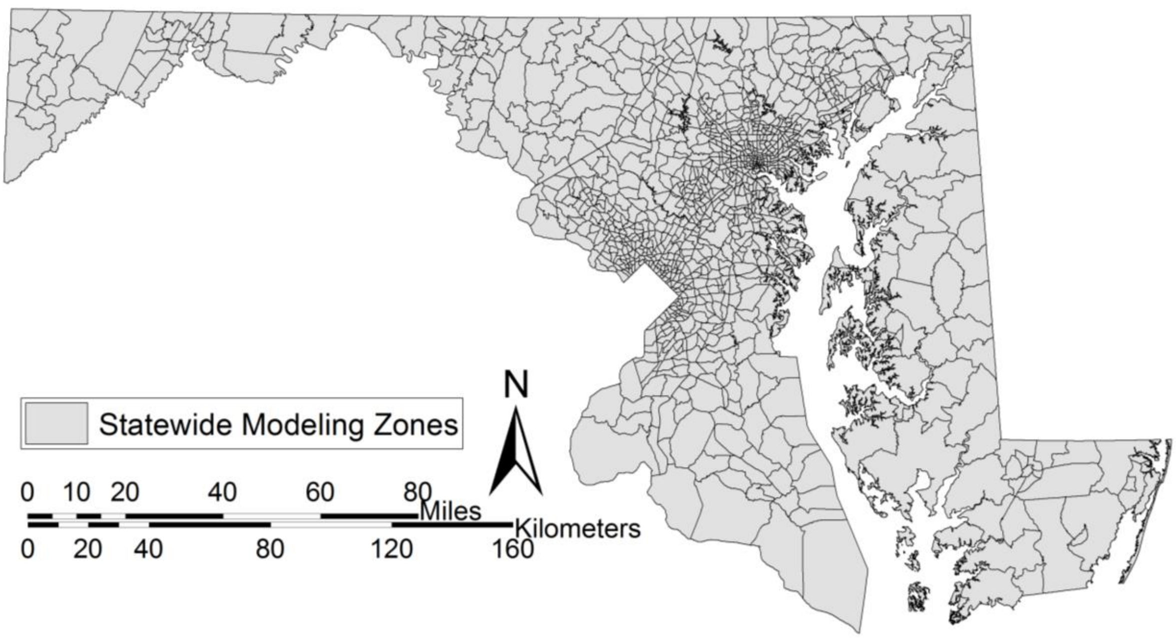


Figure 3. Maryland Statewide Modeling Zone (SMZ) structure

Each of the SMZs is associated with a total number of households stratified by five income groups. There are a total of 2.13 million households in the study area. A total of 6.20 million trips were produced on a daily basis. The proposed framework is applied to the large multimodal Washington-Baltimore transportation network. The transit network is managed by two of the largest transit systems in the country: Washington Metropolitan Area Transit Authority (WMATA), and Maryland Transit Administration (MTA). The WMATA system includes the Metrorail (rapid transit), Metrobus (fixed bus route), and MetroAccess (paratransit). MTA operates or manages the Baltimore Light Rail, Metro Subway, and commuter MARC Train. It also operates and extensive bus service consisting of 77 routes. The regional transit system has many connections to other local bus operators including the Charm City Circulator, Howard County Transit, Connect-A-Ride, Annapolis Transit, Rabbit Transit, Ride-On, and TransIT.

Details of the travel demand model are not presented in this paper for brevity, but can be found in Mishra et al. (2013). A summary of the study area household and travel characteristics is provided in Table 2.

Table 2. Household and Travel by Income Group

Income	Households		Vehicle Trips		Transit Trips		Mode Split	
	Total	Percent	Total	Percent	Total	Percent	Car	Transit
< $29,000	396,248	18.64%	588,706	10.50%	98,919	17.13%	85.61%	14.39%
$30,000 - $59,999	496,809	23.37%	1,281,645	22.86%	117,403	20.34%	91.61%	8.39%
$60,000 - $99,999	532,546	25.05%	1,401,486	25.00%	135,087	23.40%	91.21%	8.79%
$100,000 - $149,999	372,523	17.52%	1,244,234	22.19%	100,929	17.48%	92.50%	7.50%
$150,000+	327,787	15.42%	1,090,297	19.45%	124,987	21.65%	89.72%	10.28%

To measure the welfare effects of changes in the price of gas or road pricing the average auto efficiency for each income class of road user is incorporated into the travel demand model and welfare formula. To calculate the average MPG, sample data on fuel efficiency from the 2009 NHTS was used (EIA, 2011). The 2009 NHTS was the first year since 1993, that MPG was calculated. Two variables represent a range of efficiency. The first is an Energy Information Administration (EIA) measurement based on stated annual mileage and fuel expenditures. The second is the Environmental Protection Agency (EPA) rated mileage based on the age, make and model of the vehicle reported in the travel survey. The results of a sample of 287,424 valid survey responses are weighted and grouped based on household income. The NHTS household income categories are easily aggregated into the travel demand models, however the NHTS groups all incomes above $100,000 into a single category, while the travel model has a separate range for income equal to or above $150,000. For this study it is assumed that MPG for the final two income groups are the same. The average of the EIA and EPA estimates is used in the travel model for five light and medium duty vehicle types. Light duty vehicle types refer to passenger cars and small trucks. Medium duty vehicle types refer to trucks with four axles or less. Motorcycles, RVs and other heavy duty vehicle types where excluded from the calculation. We assume that changes in the gas tax will not affect the average fleet fuel economy. The rates reported in Table 3 are held constant for each scenario.

Table 3. MPG by Income category

Model	COUNT		EIA MPG		EPA MPG		Average	
Income Ranges	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
< $29,000	56,441	44,856,863	18.81	19.2	26.01	26.43	22.41	22.82
$30,000 - $59,999	82,099	57,435,223	20.26	20.67	26.14	26.45	23.2	23.56
$60,000 - $99,999	76,838	51,543,260	20.99	21.01	26.47	26.61	23.73	23.81
$100,000 - $149,999	72,046	44,853,210	21.22	21.48	26.54	26.8	23.88	24.14
$150,000+	n/a	n/a	21.22	21.48	26.54	26.8	23.88	24.14

Changes in the gas tax result in a change in each traveler's auto operating cost. As Figure 1 shows, this cost is an important parameter in the destination and mode choice models. Table 4 presents AOC cost for each traveler by income class and scenario based on a combination of VOT and MPG. VOT was estimated using a recently conducted National Household Travel Survey (NHTS) add-on product for the Washington-Baltimore region.

Table 4. Calculated Auto Operating cost for scenarios

			Scenario Auto Operating Cost (dollars per mile)					
Income Range	VOT $/h	MPG	Base	Replace Gas Tax w/VMT Tax	Simple Gas Tax Increase	Simple VMT Tax Increase	VMT Tax Revenue Recycling	VMT Tax Transit Subsidy
< $29,000	5.04	22.82	$0.16	$0.15	$0.17	$0.15	$0.14	$0.15
$30,000 - $59,999	15.00	23.56	$0.16	$0.15	$0.16	$0.15	$0.13	$0.15
$60,000 - $99,999	25.02	23.81	$0.16	$0.15	$0.16	$0.15	$0.13	$0.15
$100,000 - $149,999	30.00	24.14	$0.16	$0.15	$0.16	$0.15	$0.13	$0.15
$150,000+	63.84	24.14	$0.16	$0.15	$0.16	$0.15	$0.13	$0.15

5. Results

We measure the distributional impact that results from several scenarios focused primarily on road pricing and revenue use. The two major types of distributional analytical metrics we deploy are traveler welfare (or consumer surplus) and travel time savings. The results of the analysis are presented below for five income groups and three area types: urban, suburban and rural.

5.1 Changes in Traveler Welfare

Table 5 reports the change in traveler welfare for each of the five pricing scenarios, stratified by traveler income group. In each case the results are reported as per capita (the marginal effect for each traveler) annual consumer surplus. It is worth noting that the results indicate replacing the Maryland state gas tax with a VMT that is equivalent to the per mile cost of gas for the average fleet efficiency is a small (per traveler) net benefit for the three lowest-income groups, but results in a negative benefit for the two highest income traveler groups. Low-income travelers benefit from a reduction in the per-mile cost of travel. The average fuel efficiency to which the VMT tax is indexed is 23.69 while all three income groups have an average efficiency lower than the average, resulting in a lower per-mile cost of travel. Higher income travelers are hindered in two ways and thus have a lower consumer surplus. First, the VMT tax is indexed to fuel efficiency that is slightly higher than the average 24.14 mpg of higher income groups. Second, the reduction in travel cost to lower-income groups induces more travel by personal vehicle over public transit by lower-income travelers, resulting in a slight increase in congestion. Higher income groups have higher values of time and are therefore more sensitive to the added travel time. This further reduced higher income group welfare.

Simply increasing the state gas tax, reduces consumer surplus of all travelers, as expected. An increase in the gas tax has the largest impact on middle-income travelers, that is, travelers with a household income between $60,000 and $99,999 but the lowest-income group closely follows with a similar reduction in welfare. Higher income travelers fair the best with a gas tax increase as they drive most efficient vehicles. They also benefit from lower-income groups switching modes to public transit. Conversely, an equal increase in the VMT tax has a decidedly different impact than a change in the gas tax. Reducing the state gas tax and increasing the VMT tax only reduced the welfare of the lowest-income group by $8.50 per year. On the other hand, the highest income group has a welfare reduction of over $200 per year. This occurs because higher income travelers have on average drive more fuel-efficient vehicles. When the taxing structure is no longer tied to vehicle efficiency the higher income groups, that also typically drive more, will experience the biggest reduction in welfare.

Table 5 Change in Per Capita Annual Traveler Welfare, by income

Scenario/Income	< $29,000	$30,000 - $59,999	$60,000 - $99,999	$100,000 - $149,999	$150,000 +
Replace Gas Tax w/VMT Tax	$27.10	$14.60	$1.10	-$34.17	-$173.17
Simple Gas Tax Increase	-$47.25	-$46.68	-$47.70	-$41.03	-$10.75
Simple VMT Tax Increase	-$8.50	-$20.77	-$35.68	-$74.72	-$212.47
VMT Tax Revenue Recycling	$126.89	$132.12	$49.82	-$13.27	-$313.90
VMT Tax Transit Subsidy	$39.49	$31.78	$25.29	$38.33	$46.98

The use of revenue from road pricing schemes can also have a significant impact on travelers. We simulate the effect of using some of the revenue generated from a VMT tax to reduce the retail cost of a federal gas tax. Recycling VMT charge revenue in this way has a significantly positive impact on the lowest-income travelers. At the same time, the effect of revenue recycling reduces the welfare of the highest two income groups with a significant (relative to the other scenario impacts) reduction in welfare for the highest income group.

The only scenario and use of revenue that results in a welfare gain for all income groups is using VMT tax revenue to pay for a 20 percent transit fare subsidy. In this case, the subsidy is provided across the board for all travelers. The effect of this subsidy results in the greatest welfare gain for the high-income group, followed by the second largest welfare gain for the lowest-income group. Higher income groups benefit not just from an increase in travel time on the highway, but from a reduction in fare for urban travel.

Table 6 shows the annual traveler welfare by various area types. The procedure for determining three area types is explained in Chakraborty and Mishra (2013). When gas tax is replaced by a VMT tax, rural residents have the greatest reduction in total welfare. Rural travelers tend to travel more miles on average than suburban and urban residents. When the gas tax is replaced with a VMT tax, rural residents have a small but significant welfare reduction. A gas tax increase is a dis-benefit to the rural drivers, but has a smaller impact on suburban and urban residents. Because of number of choices in terms of alternative modes that are available to urban residents simple gas tax increase is the least detrimental to urban residents. Increasing the VMT tax above the indexed rate of the average fuel economy hurts rural residents the most, but also has the most negative impact on urban residents among the other scenarios. Using VMT tax revenue to reduce the federal gas tax has a small but positive impact on rural travelers and a very small negative impact on suburban and urban residents. Since rural drivers travel the most and typically have the least efficient vehicles, a tax reduction is on average positive. For suburban an urban drivers, the amount induced extra travel and its congestion effects make revenue recycling a detriment to welfare. Subsidizing rural transit has a much larger, positive impact on rural drivers than for urban residents. This effect can be traced to a trade-off in behavior in rural areas from personal vehicle travel to transit. Urban systems already have a high level of transit utilization so subsidization through a local VMT tax has much less impact.

Table 6 Change in Per Capita Annual Traveler Welfare, by location

Scenario/Area Type	Urban	Suburban	Rural
Replace Gas Tax w/VMT Tax	-$1.99	-$5.72	-$25.19
Simple Gas Tax Increase	-$2.06	-$5.04	-$31.58
Simple VMT Tax Increase	-$5.37	-$16.35	-$48.71
VMT Tax Revenue Recycling	-$0.37	-$4.10	$0.81
VMT Tax Transit Subsidy	$9.85	$12.80	$13.73

Table 7 shows change in per capita annual traveler welfare by income and location. In replacing gas tax with VMT high-income travelers are net losers in every location but particularly in rural locations. The biggest benefit accrues to low-income rural travelers. They have the least fuel efficient vehicles and require the most driving compared to low-income drivers in other locations. A gas tax increase affects drivers more the farther way they are from the urban area. Rural drivers of all incomes are affected in nearly the exact same way (about $35 for the first 4 income groups). In a simple VMT tax increase high-income urban travelers are negatively affected by an increase in the VMT tax, but not as badly as high-income rural drivers. Using VMT tax revenue to reduce the federal retail gas tax burden results in gains for the three lowest-income groups in all locations. For the top two highest-income groups, the effect has a negative impact in welfare. This is primarily the result of more lower-income vehicle trips due to the reduced travel cost, which slows traffic flow with a larger negative effect for high-VOT travelers. High-income urban and suburban drivers gain the most from a transit subsidy. As transit fares are reduced, many more lower-income drivers switch from personal vehicle travel to transit. This increases traffic flow, reducing the amount of time these higher-income drivers spend traveling, resulting in a welfare gain. This averaged gain is somewhat mitigated by an already high level of transit ridership. When area with very low ridership, such as rural locations see reductions in transit cost, these areas tend to experience higher welfare gains.

Table 7 Change in Per Capita Annual Traveler Welfare, by income and location

Scenario/Income	Replace Gas Tax w/VMT Tax	Simple Gas Tax Increase	Simple VMT Tax Increase	VMT Tax Revenue Recycling	VMT Tax Transit Subsidy
Urban					
< $29,000	$2.40	-$3.52	-$0.26	$10.25	$10.54
$30,000 - $59,999	$1.79	-$3.31	-$0.84	$11.93	$8.50
$60,000 - $99,999	$1.23	-$3.01	-$1.96	$5.39	$6.26
$100,000 - $149,999	-$2.28	-$1.94	-$5.63	-$1.36	$10.56
$150,000+	-$13.10	$1.46	-$18.14	-$28.07	$13.41
Suburban					
< $29,000	$4.93	-$8.68	-$2.12	$23.39	$14.20
$30,000 - $59,999	$3.59	-$8.31	-$3.92	$26.13	$10.88
$60,000 - $99,999	$2.46	-$7.63	-$7.13	$10.20	$8.42
$100,000 - $149,999	-$5.60	-$5.14	-$17.29	-$6.01	$13.47
$150,000+	-$33.99	$4.54	-$51.29	-$74.22	$17.01
Rural					
< $29,000	$19.77	-$35.06	-$6.12	$93.25	$14.75
$30,000 - $59,999	$9.22	-$35.06	-$16.00	$94.07	$12.40
$60,000 - $99,999	-$2.59	-$37.06	-$26.59	$34.22	$10.62
$100,000 - $149,999	-$26.29	-$33.95	-$51.81	-$5.90	$14.30
$150,000+	-$126.08	-$16.75	-$143.05	-$211.61	$16.57

5.2 Changes in Travel Time Variability

Changes in travel time on highway links can have a significant impact on the predictability of movement of people and goods across a network. Travelers can benefit when travel times are reduced either as a result of network investments or reductions in congestion (possibility from changes in travel cost). This benefit is estimated through the monetization of travel time savings, that is, applying different users' value of time to the changes in travel time.

Table 8 shows the change in monetized annual travel time savings for individual travelers in each income group under all five scenarios. When the gas tax is replaced with a VMT tax a trend quite opposite to the effect observed for traveler welfare emerges. Higher-income travelers benefit the most in terms of travel time savings from replacing the state gas tax with a VMT tax. This is because lower-income travelers have a lower VOT, so changes in travel time have little effect on these lower-income travelers. Increasing the state gas tax has a very small impact compared to the impact on reliably from increasing the VMT tax. This difference is so pronounced, because the VMT tax results in a larger reduction in VMT and VHT, indicators of changes in travel time (see Table 7). Either way revenues from a VMT tax are used, has the biggest impact in high-income travelers, however a subsidy to transit has the highest impact. At the lowest-income group, either use of the revenue has about the same effect.

Table 8 Change in Per Capita Annual Travel Time Savings, by income

Scenario/Area Type	< $29,000	$30,000 - $59,999	$60,000 - $99,999	$100,000 - $149,999	$150,000 +
Replace Gas Tax w/VMT Tax	$18.77	$60.55	$111.07	$137.66	$329.49
Simple Gas Tax Increase	$7.95	$35.58	$68.41	$84.28	$200.26
Simple VMT Tax Increase	$17.99	$79.26	$165.94	$215.10	$673.17
VMT Tax Revenue Recycling	$28.74	$91.62	$154.48	$185.45	$399.88
VMT Tax Transit Subsidy	$28.46	$109.95	$237.35	$316.65	$964.04

Statewide VMT and vehicle hours traveled (VHT) for all the scenarios are presented in Table 9. In comparison to the Base Case, all scenarios resulted in lower VMT and VHT. However, the largest reduction is observed in the VMT tax based transit subsidy scenario. Because of the transit subsidy, travelers with access to transit prefer not to drive a private vehicle; leading to a reduction in VMT. VMT tax revenue recycling has the least effect on VMT and VHT reduction.

Table 9 Changes in Daily Vehicle Miles Traveled and Vehicle Hours of Travel

Scenario	Total (million)		Percent change	
	VMT	VHT	VMT	VHT
Base Case	149	18,109	N/A	N/A
Replace Gas Tax w/VMT Tax	147	17,875	-1.03%	-1.29%
Simple Gas Tax Increase	148	17,990	-0.51%	-0.66%
Simple VMT Tax Increase	146	17,641.	-2.06%	-2.58%
VMT Tax Revenue Recycling	148	18,000	-0.50%	-0.60%
VMT Tax Transit Subsidy	145	17,601	-2.22%	-2.81%

Per capita annual travel time savings by various urban typologies is shown in in Table 10. Replacing state gas tax with VMT tax has a positive effect on all locations, but especially for suburban travelers. For a simple gas tax increase, rural travelers gain the most from a gas tax increase, but the effect is small for all locations. A simple VMT tax increase has very little impact on urban travelers, but a nearly equal travel time savings effect of suburban and rural drivers. Suburban travelers are the primary benefactors of a revenue-recycling scheme. Subsidizing transit has a small impact on travel time savings for urban travelers; this is because they travel more by transit. The biggest benefit for urban travelers comes not from travel time savings benefits but from the previously mentioned gains in consumer surplus.

Table 10 Change in Per Capita Annual Travel Time Savings, by location

Scenario/Income	Urban	Suburban	Rural
Replace Gas Tax w/VMT Tax	$23.95	$210.84	$131.00
Simple Gas Tax Increase	$10.33	$60.61	$116.60
Simple VMT Tax Increase	$46.22	$202.17	$318.86
VMT Tax Revenue Recycling	$6.62	$534.04	$39.30
VMT Tax Transit Subsidy	$89.19	$394.13	$394.70

Table 11 shows changes in per capita travel time savings stratified by traveler income and area types. For replacing gas tax with a VMT tax, higher-income suburban and rural travelers gain the most travel time savings. The effect of raising the Maryland gas tax has a relatively small impact on urban travelers but the impact increases as the location moves to suburban and then rural areas. Travel time savings is a function of travel time variance. Changes in taxing structure have a lower impact on overall travel demand in urban areas than in suburban and rural areas. This is a function of the need to travel in urban areas regardless of cost. As a result, changes in the taxing structure have a much larger impact on the variability in suburban and rural areas, thus travel time savings are the greatest for these travelers. It is the highest-income rural and suburban travelers that benefit the most from a transit subsidy. This is because these users are not likely to take transit, rather they reap the greatest benefit for their typically longer distance travel and lower amounts of delay. With a high VOT and long distance travel, the highest-income travelers benefit the most from even small decreases to travel time.

Table 11 Change in Per Capita Annual Travel Time Savings, by income and location

Scenario/Income	Replace Gas Tax w/VMT Tax	Simple Gas Tax Increase	Simple VMT Tax Increase	VMT Tax Revenue Recycling	VMT Tax Transit Subsidy
Urban					
< $29,000	$3.84	$0.51	$0.75	$0.09	$1.05
$30,000 - $59,999	$12.52	$5.66	$7.46	$2.44	$7.88
$60,000 - $99,999	$21.39	$9.78	$14.30	$5.78	$35.12
$100,000 - $149,999	$25.85	$11.61	$21.13	$6.93	$62.75
$150,000+	$56.13	$24.08	$187.44	$17.83	$339.14
Suburban					
< $29,000	$36.37	$6.75	$24.74	$94.39	$55.02
$30,000 - $59,999	$111.27	$31.19	$87.91	$287.81	$166.57
$60,000 - $99,999	$189.28	$55.79	$151.10	$480.85	$302.93
$100,000 - $149,999	$227.75	$67.05	$186.46	$576.28	$387.22
$150,000+	$489.55	$142.28	$560.66	$1,230.84	$1,058.91
Rural					
< $29,000	$15.14	$11.51	$21.03	$4.09	$24.65
$30,000 - $59,999	$52.08	$49.79	$102.65	$19.44	$118.98
$60,000 - $99,999	$104.15	$98.39	$233.31	$34.63	$281.45
$100,000 - $149,999	$133.02	$122.28	$306.67	$42.10	$379.25
$150,000+	$350.63	$301.04	$930.62	$96.22	$1,169.18

6. Discussion and Conclusions

This paper examines changes in consumer surplus and travel time savings as a result of replacing the Maryland state gas tax with a mileage-based road pricing mechanism. While there is a growing body of literature that examines the distributional effects of replacing some portion of the gas tax with a mileage-based or VMT tax, few do so with the aid of a large-scale behaviorally robust travel demand models. This paper contributes to the literature by developing just such an analysis. Five pricing scenarios are considered to analyze alternative options for revenue generation. Two performance measures, traveler welfare and travel time savings are computed for each scenario.

Results are analyzed by five income groups of travelers and three area types (urban, suburban, and rural). The complete model set was applied in the state of Maryland using an advanced travel demand model.

In addition to the base case, five scenarios are developed including: (1) Replace Gas Tax with a VMT tax, (2) Simple Gas Tax Increase, (3) Simple VMT Tax Increase, (4) VMT Tax Revenue Recycling, and (5) VMT Tax Transit Subsidy. When each scenario was compared to the Base Case it was found that all of the changes have a proportionately smaller impact on annual per capita consumer surplus, compared to the value of travel time savings. Replacing the state gas tax with a VMT tax can have a positive impact on traveler welfare, particularly for lower-income groups and rural residents. Increasing either the gas tax or VMT tax will result in mixed effects for different income groups. Likely, a VMT tax increase would be the least detrimental to welfare, especially for low-income groups.

The proposed pricing scenarios can be beneficial to identify potential revenue generation sources. Using revenue obtained from a VMT tax to reduce the federal retail gas tax burden has a significant impact (relative to the other scenarios) but subsidizing transit fares appears to be the only use that positively benefits all travelers. Using the revenue from a VMT tax can significantly benefit all drivers, but has different magnitudes of effect for income and location depending on the use (Burris et al. 2013). The best use may be a mix of revenue recycling and transit fare subsidy; not quite to the extremes simulated in this paper. Perhaps the best option in terms of traveler welfare and travel time savings, if revenue re-use is not an option, is to simply replace the state gas tax with a revenue neutral VMT tax. The option provides a significant welfare improvement for income groups below $100,000 and a strong travel time savings benefit for higher-income groups.

This paper provides several advantages for application and practice. First, it provides new insight for development of prudent strategies to replace the existing state gas tax. Second, a procedural application of five scenarios is offered that incorporates decision maker's strategies to examine travelers' response. Third, an application of the proposed methodology in a real world multimodal transportation network that compares model results and quantifies the benefits of each model. Fourth, the estimation of performance measures such as traveler welfare, travel time savings, VMT and VHT for each scenario stratified by income groups and area types. Results from each model provide an array of decision-making options as strategies for replacing the current gas tax and exploring options from viewpoint of travelers. In this paper, a trip-based model is used to obtain effects of alternate pricing strategies while each individual characteristic is aggregated to zonal levels. To obtain each individual's trip making behavior and elasticity to such policy changes a micro-level land use and tour-based travel demand model options can be explored in the future along with more localized network measures such a changes in individual mode preference, traveler utility and travel time reliability.

Appendix

Base Case

A user equilibrium assignment is employed to model user behavior for the base case. The objective of the model was to simulate each origin-destination (O-D) demand pair till the travel-cost/travel-time on all used routes of the road network becomes equal (Sheffi 1984). The travel time function $t_a(.)$ is specific to a given link 'a' and the most widely used model is the Bureau of Public Roads (BPR) function given by

$$t_a(x_a) = t_o\left(1 + \alpha_a \left(\frac{x_a}{C_a}\right)\right)^{\beta_a} \quad (1)$$

where to(.) is free flow time on link 'a', and α_a and β_a are constants (and vary by facility type). C_a is the capacity for link a. In the base model the objective is minimization of total system travel time. Emission is not a component of the base case.

All Other Scenarios

Pricing for all other scenarios is incorporated into the travel cost function. The revised cost function becomes as follows:

$$u_a^I(x_a, \sigma) = t_a(x_a) + \frac{\sigma l_a}{\gamma^c \vartheta} \quad (2)$$

where, σ is the gas price in dollars per mile (as a ratio of dollars per gallon), $l_a$is the link length in miles, γ^c is the VOT in \$/hr, and ϑ is the automobile gasoline efficiency in miles per gallon. Auto Operating Cost (AOC) is another component, which is considered in the mode and destination choice sections of the model. For brevity details of the destination choice and mode choice are not presented in this paper, but can be found in Mishra et al. (2012). A higher gas price will result in a higher AOC and therefore will make auto travel more expensive.

Analytically, the user cost function can be stated as the following to incorporate the VMT-based tax.

$$u_a^{II}(x_a, e_a,) = t_a(x_a) + \frac{\theta_a l_a}{\gamma^c} \quad (3)$$

where, θ_a is the VMT tax in \$/mile for link a, $l_a$is the link length in miles, and γ^c is the VOT in \$/hour. In traffic assignment procedure, the user cost shown in equation (7) can be used in equation (1).

Welfare

We estimate consumer surplus using the rule of half which is an approximation adapted for matrix-based travel models of the Marshallian consumer surplus (Geurs, 2006).

$$CS_{ij}^{r} \cong .5\left(O_{ij}^{b,r} f_{ij}^{b,r} + O_{ij}^{r} f_{ij}^{r}\right)\left(t_{ij}^{b}\left(x_{ij}^{b}\right) - t_{ij}(x_{ij})\right) \quad (4)$$

where O is the vehicle occupancy (in this case either 1, 2 or 3) of vehicles traveling between origin and destination *i-j*, f is the traffic flow between origin and destination *i-j* and the $t_{ij}(x_{ij})$ is the generalized travel cost between zone pairs on the least cost path after highway assignment. This formulation of traveler welfare assumes a linear demand curve (Geurs, 2006).

Travel Time Variability

The monetized value of travel time savings is estimated as follows.

$$TTS = \sum v_{ij} = \sum\left(\left[\frac{\left(\sum t_{r_a}^{c} - \overline{t_{r_a}^{c}}\right)^2}{n-1}\right] \times \left(1 + \alpha_a \left(y + \frac{x_a}{C_a}\right)\right)^{\beta_a}\right) \quad (5)$$

where *TTS* is the overall travel time savings measure, v_{ij} is the variance in congested travel time of all paths between all origins and destinations, t^{c}_{ra} is the congested travel time on the links (a) that form a given path, $\overline{t_{r_a}^{c}}$ is the mean contested travel time between the base and new scenario an n is the number of links along the given path. The first function is the congested travel time variance. The parameters α_a y and β_a are a modified version of the BPR function.

References

Chakraborty, A., and Mishra, S. 2013. Land Use and Transit Ridership Connections: Implications for State-level Planning Agencies. *Land Use Policy*, 30(1), pp. 458-469.

Abou-Zeid, M., Ben-Akiva, M., Tierney, K., Buckeye, K., & Buxbaum, J. (2008). Minnesota Pay-as-You-Drive Pricing Experiment. *Transportation Research Record: Journal of the Transportation Research Board*, *2079*(-1), 8–14. doi:10.3141/2079-02

Arnott, R., Palma, A. de, & Lindsey, R. (1994). The Welfare Effects of Congestion Tolls with Heterogeneous Commuters. *Journal of Transport Economics and Policy*, *28*(2), 139–161. doi:10.2307/20053032

Balducci, P. (2011). *Costs of Alternative Revenue-generation Systems* (Vol. 689). Transportation Research Board. Retrieved from http://books.google.com/books?hl=en&lr=&id=ruSQSByFK1cC&oi=fnd&pg=PP1&dq=Costs+of+Alternative+Revenue-Generation+Systems&ots=vb2DEaPD0O&sig=wP0zbN_4aqQ9aBKeeU24hi7xUCI

Bertini, R. L., & Rufolo, A. M. (2004). Technology considerations for the implementation of a statewide road user fee system. *Economic Impacts of Intelligent Transportation Systems: Innovations and Case Studies. Research in Transportation Economics*, *8*, 337–361.

Bordoff, J. E., & Noel, P. J. (2008). *The impact of pay-as-you-drive auto insurance in california*. Brookings Institution. Retrieved from http://www.brookings.edu/~/media/Research/Files/Papers/2008/7/payd%20california%20bordoffnoel/07_payd_california_bordoffnoel.pdf

Burris, M., Lee, S., Geiselbrecht, T., & Baker, R. (2013). *Equity Evaluation of Sustainable Mileage-Based User Fee Scenarios* (Technical Report No. SWUTC/14/600451-00007-1). Southwest Region University Transportation Center. Retrieved from http://d2dtl5nnlpfr0r.cloudfront.net/swutc.tamu.edu/publications/technicalreports/600451-00007-1.pdf

Button, K. (1995). Road pricing as an instrument in traffic management. In *Road Pricing: Theory, Empirical Assessment and Policy* (pp. 35–55). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-94-011-0980-2_3

Cervero, R., & Hansen, M. (2002). Induced travel demand and induced road investment: a simultaneous equation analysis. *Journal of Transport Economics and Policy*, 469–490.

Ecola, L., & Light, T. (2009). Equity and Congestion Pricing. *Rand Corporation*, 1–45.

EIA, E. I. A. (2011). *Methodologies for estimating fuel consumption using the 2009 national household travel survey*. Federal Highway Administration. Retrieved from http://nhts.ornl.gov/2009/pub/EIA.pdf

Eliasson, J., & Mattsson, L.-G. (2006). Equity effects of congestion pricing: Quantitative methodology and a case study for Stockholm. *Transportation Research Part A: Policy and Practice*, *40*(7), 602–620. doi:10.1016/j.tra.2005.11.002

Felder, S., & van Nieuwkoop, R. (1996). Revenue recycling of a CO2 tax: Results from a general equilibrium model for Switzerland. *Annals of Operations Research*, *68*(2), 233–265.

Forkenbrock, D. J. (2005). Implementing a mileage-based road user charge. *Public Works Management & Policy*, *10*(2), 87–100.

Franklin, J. P. (2007). Decomposing the distributional effects of roadway tolls. In *Transportation Research Board 86th Annual Meeting*. Retrieved from http://trid.trb.org/view.aspx?id=802511

Fridstrøm, L., Minken, H., Moilanen, P., Shepherd, S., & Vold, A. (2000). Economic and equity effects of marginal cost pricing in transport. *AFFORD Deliverable A*, *2*. Retrieved from http://vplno1.vkw.tu-dresden.de/psycho/projekte/afford/download/AFFORDdel2a.pdf

Fuetsch, M. (2009). National VMT tax system could use current technology, Minn. study says. *Transport Topics*, (3862). Retrieved from http://trid.trb.org/view.aspx?id=901753

Geurs, K. (2006). *Accessibility, land use and transport*. Eburon Uitgeverij B.V.

Glaister, S., & Graham, D. J. (2005). An evaluation of national road user charging in England. *Transportation Research Part A: Policy and Practice*, *39*(7), 632–650.

Greene, D. L. (2011). What is greener than a VMT tax? The case for an indexed energy user fee to finance us surface transportation. *Transportation Research Part D: Transport and Environment*, *16*(6).

Kim, D. S., Porter, D., & Wurl, R. (2002). Technology Evaluation for Implementation of VMT Based Revenue Collection Systems. *Salem, OR: Oregon Department of Transportation. Report No. FHWA-OR-VP-03-07*. Retrieved from http://www.oblpct.state.or.us/ODOT/HWY/OIPP/docs/OSU_VMT_Final_Report_WEB.pdf

Kim, D. S., Porter, J. D., Whitty, J., Svadlenak, J., Larsen, N. C., Capps, D. F., … Hall, D. D. (2008). Technology evaluation of Oregon's vehicle-miles-traveled revenue collection system: Lessons learned. *Transportation Research Record: Journal of the Transportation Research Board*, *2079*(1), 37–44.

Kockelman, K., Fagnant, D., Nichols, B., & Boyles, S. (2012). A Project Evaluation Toolkit (PET) for Abstracted Networks. Retrieved from http://trid.trb.org/view.aspx?id=1243218

Levinson, D. (2010). Equity Effects of Road Pricing: A Review. *Transport Reviews*, *30*(1), 33–57. doi:10.1080/01441640903189304

Margiotta, R., Lomax, T., Hallenbeck, M., Dowling, R., Skabardonis, A., & Turner, S. (2013). Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. *SHRP 2 Report*, (S2-L03-RR-1). Retrieved from http://pubsindex.trb.org/view/2013/M/1226380

May, A. D., & Milne, D. S. (2000). Effects of alternative road pricing systems on network performance. *Transportation Research Part A: Policy and Practice*, *34*(6), 407–436.

Md. gas tax: The cost of doing nothing. (n.d.). *Baltimore Sun*. Retrieved March 21, 2013, from http://articles.baltimoresun.com/2011-03-10/news/bs-ed-gas-tax-20110310_1_gas-tax-price-spike-gasoline-prices

NTD. (2011). *National Transit Database: TS 2 Operating Expenses, Service Supplied and Consumed Dataset* (No. TS2). Washington DC. Retrieved from http://www.ntdprogram.gov/ntdprogram/data.htm

NYSDOT Task Assignment, C. (2012). Mileage-Based User Fees: Prospects and Challenges. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.258.8533&rep=rep1&type=pdf

Parry, I. W. (2005). Is Pay-as-You-Drive insurance a better way to reduce gasoline than gasoline taxes? *American Economic Review*, 288–293.

Parry, I. W. H., & Bento, A. (2001). Revenue Recycling and the Welfare Effects of Road Pricing. *Scandinavian Journal of Economics*, *103*(4), 645–671. doi:10.1111/1467-9442.00264

Parry, I. W. H., & Small, K. A. (2005). Does Britain or the United States Have the Right Gasoline Tax? *The American Economic Review*, *95*(4), 1276–1289. doi:10.1257/0002828054825510

Peters, J. R., & Kramer, J. K. (2012). Just Who Should Pay for What? Vertical Equity, Transit Subsidy and Road Pricing: The Case of New York City. *Journal of Public Transportation*, *15*(2), 117–136.

Santos, G., & Rojey, L. (2004). Distributional impacts of road pricing: The truth behind the myth. *Transportation*, *31*(1), 21–42.

Shackleton, R., Shelby, M., Cristofaro, A., Brinner, R., Yanchar, J., Goulder, L., … Kaufman, R. (1992). *The efficiency value of carbon tax revenues*. US Environmental Protection Agency Washington DC. Retrieved from http://emf.stanford.edu/files/pubs/22440/WP1208.pdf

Smalkoski, B., & Levinson, D. (2005). Value of time for commercial vehicle operators in Minnesota. In *Journal of the Transportation Research Forum* (Vol. 44, pp. 89–102).

Small, K. A. (1992). Using the revenues from congestion pricing. *Transportation*, *19*(4), 359–381. doi:10.1007/BF01098639

Sorensen, P. A., & Taylor, B. D. (2005). Review and synthesis of road-use metering and charging systems. *Transportation Research Board*. Retrieved from http://its.ucla.edu/research/rpubs/Sorensen_Taylor_v8.pdf

Starr McMullen, B., Zhang, L., & Nakahara, K. (2010). Distributional impacts of changing from a gasoline tax to a vehicle-mile tax for light vehicles: A case study of Oregon. *Transport Policy*, *17*(6), 359–366. doi:10.1016/j.tranpol.2010.04.002

Strand, J. (1998). Pollution taxation and revenue recycling under monopoly unions. *The Scandinavian Journal of Economics*, *100*(4), 765–780.

Verhoef, E. T. (2002). Second-best congestion pricing in general networks. Heuristic algorithms for finding second-best optimal toll levels and toll points. *Transportation Research Part B: Methodological*, *36*(8), 707–729.

Weatherford, B. (2011). Distributional Implications of Replacing the Federal Fuel Tax with Per Mile User Charges. *Transportation Research Record: Journal of the Transportation Research Board*, *2221*(-1), 19–26. doi:10.3141/2221-03

Welch, T. F., & Mishra, S. (*Forthcoming*). Envisioning an emission diet: application of travel demand mechanisms to facilitate policy decision making. *Transportation*, 1–21. doi:10.1007/s11116-013-9511-4

Zhang, L., & McMullen, B. S. (2008). Statewide distance-based user charge: Case of Oregon. In *Transportation Research Board 87th Annual Meeting*. Retrieved from http://trid.trb.org/view.aspx?id=848406

Zhang, L., McMullen, B. S., Valluri, D., & Nakahara, K. (2009). The short-and long-run impact of a vehicle mileage fee on income and spatial equity. *Transportation Research Record: Journal of the Transportation Research Board, 2115*, 110–118.