Do U.S. Households Favor Higher Efficiency Vehicles When Fuel Prices Increase?

Valerie J. Karplus

Submission for Dennis J. O'Brien USAEE/IAEE Best Student Paper Award

July 8, 2010

Households owning multiple vehicles could reduce the impact of a fuel price increase by switching to increase reliance on their more fuel-efficient vehicle(s). This paper estimates the extent of vehicle switching that occurred during the gasoline price fluctuations of 2008 to 2009 using cross-sectional household vehicle ownership and vehicle trip data from the 2009 National Household Transportation Survey, assuming household fleets remained largely fixed over the same period. First, comparison of short-run elasticities of vehicle-miles traveled (VMT) and fuel demand with respect to gasoline price show that in almost all cases gasoline demand is reduced proportionately more than VMT, suggesting that households are achieving higher efficiencies of travel. Second, vehicle switching by two-vehicle households as a function of the potential per-mile savings available was found to be modest, with every one cent increase in savings per mile of travel corresponding to an average increase fraction of miles-traveled in the most fuel efficient vehicle by 0.014. This response was found to vary significantly by household income level and by degree of urbanization. Third, the likelihood that a two-vehicle household assigned its higher efficiency vehicle to a particular trip also increased. This effect was most prevalent for trips involving daily activities (i.e. commuting, shopping or medical visits), while only vacation trips, which typically require more passenger and cargo capacity, did not show a significant effect.

1. Introduction

While many studies have asked how fuel economy influences new vehicle purchase decisions, fewer have focused on how fuel economy influences vehicle usage decisions. This response may be important for households that own multiple vehicles, since in response to a fuel price increase these households could conserve fuel and reduce increased expenditures without reducing vehicle-miles traveled (VMT) by switching to higher fuel economy vehicles. For instance, a commuter may prefer the comfort and spaciousness of a sport utility vehicle (SUV) as long as gasoline prices remain low, but switch to the car and reserve the SUV for occasional use when fuel prices rise.

Previous studies have pointed out that fuel demand is reduced more than travel demand in response to a fuel price increase. Short-run estimates of the gasoline price elasticity of demand prior to 1990 range from -0.21 to -0.34, while elasticities of demand for vehicle-miles traveled (VMT) are consistently smaller (in magnitude) ranging from -0.12 to -0.15 (see **Table 1**). Estimates available using more recent data suggest that the own-price elasticity of fuel demand has decreased considerably, with a range estimated between -0.034 to -0.077 (Hughes et al., 2006; Small & Van Dender, 2007).[1] These aggregate elasticity estimates mask diversity in household-level responses that may vary with income level, degree of urbanization, and the number and type of vehicles owned. For example households owning more vehicles tend to travel more, use more fuel, and thus would contribute disproportionately to aggregate elasticity calculations.

The discrepancy between the fuel demand and travel demand responses in both short- and long-run elasticity estimates suggests an endogenous increase in the fuel efficiency of driving in response to fuel price increases. This increase may be due to many factors, for instance, the

[1] Hughes et al. (2006) suggest the shift may be due to changes in land use, social or vehicle characteristics.

retirement of older, less-efficient vehicles, the purchase of new, more-efficient vehicles, the adjustment of driving style or speed to conserve fuel, or switching to favor higher fuel economy vehicles owned by the household. Since this last type of switching potentially requires the lowest capital cost and least amount of behavioral change, it is of interest to know how much it contributes to the household response. This type of response may grow more important if vehicles that use much less or no gasoline are adopted. A single gasoline-free vehicle may offer a household the ability to reduce fuel use dramatically depending on which household vehicle-miles it replaces. Examining the role of fuel economy in existing household vehicle usage decisions provides insight into the factors that will affect the utilization of these advanced vehicle types.

This research employs a new publically available data set on household vehicle usage in the United States, the 2009 National Household Transportation Survey, during a period of fuel price fluctuations. The gasoline price rose from $3.24 per gallon in March 2008 to $4.06 in July 2008 before falling to $1.69 in December 2008 and then gradually inching upwards in the early months of 2009 (see **Figure 1**). The data set includes information on household demographics, vehicle ownership, and vehicle utilization on a randomly assigned travel day. The relatively short time span of the survey data (fourteen months) and depressed vehicle sales leading up to and during the economic downturn provide a unique opportunity to observe the short-run, fixed fleet response to fuel prices.

This analysis is organized as follows. **Section 2** provides a brief literature review and develops a model of the household response conditional on the magnitude of the fuel economy difference between vehicles and the magnitude of the change in gasoline price. **Section 3** describes the data set and how it was used to investigate the relationship of interest. **Section 4** lays out the modeling strategy, which includes a combination of elasticity estimates for gasoline and vehicle-miles traveled with respect to gasoline price, estimates of the effect of potential savings on vehicle mileage shares, and a discrete choice analysis of the effect of potential savings on per trip vehicle switching propensity, and describes the results. **Section 5** offers some preliminary conclusions and extensions for future work.

2. Economic Theory and Background

Interest in understanding the role of energy efficiency in consumer decisions has motivated a prolific and diverse literature in economics and, to lesser extent, engineering (Hausman, 1979; Train, 1985). Much of the economics literature has focused on consumer perceptions and trade-offs between upfront costs and lifetime savings at the point of new vehicle purchase (Allcott & Wozny, 2010; Sallee & Slemrod, 2010; Klier & Linn, 2008). Others have focused on describing the engineering trade-offs associated with increasing fuel economy and other energy-requiring vehicle attributes, such as performance, size, and weight (Knittel, 2009; An & DeCicco, 2007). Since consumer vehicle purchase and use decisions are closely related (and often considered to be simultaneous), understanding the role of fuel economy in vehicle usage decisions is important and complementary to these previous studies. The effectiveness and distributional impact of policies to address local air quality, congestion, and climate change will depend on both short- and long-run vehicle usage responses (Feng et al., 2007; Bento et al., 2009; Small & Van Dender, 2007).

A. The role of household vehicle reallocation

This analysis begins with a stylized model of how the household response to a gasoline price increase could differ depending on the number of vehicles, fuel economy differences within the household vehicle fleet, and the household’s ability or willingness to reallocate mileage. Inputs to household vehicle transport include motor gasoline, the vehicle itself, and other non-fuel operating requirements (insurance and maintenance, for example). Household fleets are largely fixed in the short term, and fuel accounts for a significant percentage of total annualized vehicle ownership costs, more than 50% for most vehicle types in 2009 (AAA, 2009).

A change in fuel price increases the operating cost for some vehicles more than others, depending on the fuel economy of the vehicles in question. Fuel use is equivalent to total miles-traveled (M_T) divided by average on-road fuel economy (ē) realized by the household as shown in Equation (1). For a two-vehicle household, ē is computed in Equation (2) by weighting the efficiency of each vehicle (e_1, e_2) by the fraction of total miles it provides:

$$F = M_T/\bar{e} \quad (1)$$

$$\bar{e} = (M_1/M_T)e_1 + (M_2/M_T)e_2 \quad (2)$$

The important point here is that ē is endogenous, in part because the household is able to choose how it allocates its vehicles to meet its travel needs. The household is also able to choose its total travel distance. Small and Van Dender (2007) relate the own-price elasticity of fuel demand to the elasticities of fuel economy with respect to fuel price and of miles traveled with respect to per mile travel cost (a function of fuel price):

$$\varepsilon_{f,pf} = \varepsilon_{M_T,p_f}\left(1 - \varepsilon_{\bar{e},p_f}\right) - \varepsilon_{\bar{e},p_f} \quad (3)$$

where the first term on the right-hand side of the equation represents the interaction of vehicle-miles traveled with respect to per mile fuel cost (ε_{M_T,p_f}) with the elasticity of fuel efficiency with respect to fuel price ($\varepsilon_{\bar{e},p_f}$). The interpretation of this equation is straightforward—households can reduce fuel use by increasing the efficiency of travel or reducing miles, but higher average vehicle efficiency will, all else equal, encourage more travel. In the short run improving the elasticity of fuel efficiency with respect to fuel price includes the effect of household vehicle reallocation.[2]

B. **Constraints on the household vehicle reallocation**

The degree to which vehicle switching versus other strategies is employed by the household is likely to be constrained by household, vehicle, and trip characteristics. If the household has more members, the household's vehicles are more likely to be in use at any given time. Also, in addition to household size, the average number of passengers that need to be transported at any given time will vary, depending on the household's daily activities and trip characteristics. The number and type of vehicles owned by the household will further affect flexibility. For example, haulage or terrain requirements may necessitate the use of a more powerful or rugged vehicle, characteristics that are often negatively correlated with fuel efficiency. Urbanization is also likely to play a role, since it influences the ease with which public transit, carpooling, biking, or walking can be substituted for vehicle trips in response to higher fuel prices. Switching is also hypothesized here to vary by income category, since low income households owning vehicles likely spend a higher fraction of their income on gasoline compared to higher income households.

3. Data set and descriptive statistics

A. The National Household Transportation Survey, 2009

The National Household Transportation Survey has been conducted every five to eight years by the Federal Highway Administration (FHWA). It includes nationally-representative repeated cross-sectional data on households, vehicle ownership, and the daily travel patterns of the household members. The 2009 survey builds on the 2001 NHTS and the Nationwide Personal

[2] A household could also increase on-road fuel economy in the short run through other methods, for example through better maintenance or less aggressive driving style, which are not quantified here.

Transportation Survey (NPTS) conducted in 1969, 1977, 1983, 1990, and 1995 (FHWA, 2009a). The survey includes a record of the travel behavior of randomly-sampled households during an assigned twenty-four hour period. For each trip taken, the interviewer collects information about the purpose of the trip, means of transportation, how long the trip took, the time of day that it took place, and the day of the week on which household travel was recorded. If the trip was taken in a private vehicle, data was collected on vehicle occupancy, driver characteristics, and vehicle attributes (including make, model, and number of miles driven in a year). The total number of households included in the full data set is just over 150,000. Average monthly fuel prices were mapped to the month in which the household travel occurred, and adjusted to account for variation in state-level gasoline taxes. Sample weights were provided by the NHTS administrators to correct for non-response and other factors described in FHWA (2009a), and used in this analysis to weight observations in order to obtain representative population-level estimates.[3]

Fuel economy information for each of the vehicles owned was not directly collected as part of the NHTS. In order to match the make and model supplied for each household-owned vehicle to its fuel economy, I employed a Ward's database that reports detailed specifications on new vehicle makes and models for the model year 2008, including city and highway fuel economy (Ward's, 2007). For older vehicles not included in the database, I used make, vehicle type, and vehicle age data to calculate the average value of city and highway fuel economy, assuming a degradation factor for fuel economy of 1% per year of ownership. For per trip estimates where average travel speed was known, I used the vehicle's city or highway fuel economy to determine

[3] In late spring 2010 the NHTS announced that they were revising the sampling weights in order to improve the representativeness of the data particularly for transit trips. As of this draft, the new weights had not been published, but will be used as soon as they become available, although significant changes to the data used in this analysis are not expected.

the per mile cost savings, assuming highway fuel economy for any trip with an average travel speed over 40 miles per hour. When a trip-independent measure of per mile cost savings was required, I used the weighted harmonic average of city and highway fuel economy used by the Environmental Protection Agency fuel economy label calculations, which assumes total miles-traveled for one vehicle occurs 45% in the city and 55% on the highway (EPA, 2004).

B. Data selection for this analysis

For the first part of this analysis, elasticities are estimated for the aggregate sample and multiple subsamples of U.S. households, conditional on its decision to drive on the observed travel day. The proportion of households choosing to drive at all does not change noticeably with gasoline price (not shown) and thus the analysis is carried out conditional on the decision to utilize at least one vehicle. The number of households included in this sample was 73,321.

For the second and third parts of this analysis, I focus on sampled U.S. households that own two vehicles only. Two-vehicle households account for 41% of all households, 42% of vehicles, and 46% of vehicle-miles traveled. The distribution of households by number of vehicles owned is shown in **Figure 2**.

One drawback inherent in using this particular data set is the fact that the precise survey date was not reported for each household, but only the day of the week, month, and year. Given this reporting convention, the best proxy for fluctuations in gasoline price is the national monthly average price of motor gasoline reported by state for 2008 and 2009 (FHWA, 2008b; FHWA, 2009). A few state gasoline price observations were missing from this data set and were filled in using regional monthly gasoline prices reported by the EIA (2010). Using monthly average prices by state masks day-to-day fluctuations in gasoline price perceived by the household.

However variation due to state level taxes, which range from near zero to around 50 cents introduced an additional source of variability into the observations.

4. Model description and results

The goal of this research is to understand the extent to which within-fleet substitution formed part of the household response to the 2008-2009 gasoline price fluctuations, and to investigate whether and how household characteristics affect its magnitude. Three approaches were used to test for the existence of an effect. First, I estimate elasticities of demand for gasoline and VMT with respect to gasoline price, conditional on the income level, degree of urbanization, and the number of vehicles owned by the household. Second, I consider the relationship between fraction of household miles driven in the household's relatively high fuel economy vehicle as a fraction of total miles-traveled on the household's assigned travel day and the potential savings associated with switching. Third, I estimate a logit model to investigate the effect of per-mile savings on the choice of the high-efficiency vehicle by trip.

A. Elasticities

To find out if households reduced fuel use more than mileage as gasoline price increased, gasoline price elasticities of demand for VMT and gasoline were calculated for the aggregate sample and conditional on household characteristics. The models estimated are shown in Equations (4) and (5). Equation (4) is similar to the specification used in Hughes et al. (2006). The model estimates the relationship between gasoline price (P_i) (determined by month of observation and household state) and household gasoline use (G_i) as well as vehicle-miles traveled (VMT_i), expressed as elasticities using log-log robust ordinary least squares regression. The effect of income, household size, and whether or not household travel took place on a weekday were included as a vector of household-specific characteristics $\gamma(Z_{\mathrm{i}})$. Seasonal changes, including the effect of summer travel and possibly also economic downturn in the fall of 2008, were captured using dummy variables s_i spanning three-month periods, which were assigned according to the month in which the household travel day occurred.

(4) $$\ln G_i = \beta_0 + \beta_1 \ln P_i + \beta_2 \ln Y_i + \gamma(Z_i) + s_i + \varepsilon_i$$

(5) $$\ln VMT_i = \beta_0 + \beta_1 \ln P_i + \beta_2 \ln Y_i + \gamma(Z_i) + s_i + \varepsilon_i$$

1) Aggregate elasticity estimates

The elasticities of demand for VMT and gasoline with respect to gasoline price are reported for the aggregate sample as shown in **Table 2**. These estimates of -0.112 for VMT and -0.144 for gasoline use fall within the ranges reported by earlier studies, and are consistent with the existence of a differential response (Table 1). Positive short-run income elasticities for both gasoline demand and VMT with respect to gasoline price are consistent with previous estimates. Household size also has a significant effect on fuel use, while weekday indicates that VMT and fuel use are reduced relative to weekend travel.

2) Elasticities conditional on income level

Aggregate elasticity estimates may mask important differences in the responses of population subgroups. To find out whether subgroups might have significantly different elasticities that are not resolved in the aggregate estimates, I condition on income level and degree of urbanization. In **Table 3**, elasticities are presented conditional on household income. The lowest income category (< $25,000 per year) shows the most inelastic behavior, with the elasticity of demand for VMT not significantly different from zero. Since these households are likely the most cash-constrained, reducing fuel consumption without reducing VMT may be a particularly attractive option, especially if the proportion of vehicle-miles devoted to economically necessary (non-discretionary) activities is greater than for higher income households. As income increases, household responses generally become more elastic, consistent with the notion that reducing the number and length of car trips may be easier if those marginal miles are devoted to vacation or other discretionary trips, which can be reduced without affecting income, or for which less expensive substitute modes of transport may be available.

3) Elasticities conditional on degree of urbanization

Next I condition on the degree of urbanization. A comparison of the elasticities suggests that urban households are somewhat more elastic while rural households are less elastic in their responses to gasoline prices (measured elasticities are not significantly different from zero) (**Table 4**). Relatively higher elasticities in urban areas probably reflect the availability of public transportation, carpooling, or other substitutes for household-owned vehicle travel.

4) Elasticities conditional on vehicle ownership

Finally, the role of household vehicle ownership was considered. The log of household income, household size, the weekday dummy, and the instrument for seasonality were included in the regression. Interestingly, households owning one vehicle showed a relatively elastic response, with elasticities estimated at -0.154 for VMT and -0.181 for gasoline. Consistent with a differential response, households owning two vehicles had a significantly smaller (in magnitude) response, while households that owned three vehicles had the largest response of any category, as shown in **Table 5**.

B. The Relationship between Fraction of Miles-Traveled in the High Efficiency Vehicle and Per Mile Cost Savings

A comparison of the magnitude of elasticity estimates for VMT and gasoline demand with respect to gasoline price suggests household responses consistent with vehicle switching that may vary with household characteristics. To investigate the extent of switching, I consider only two-vehicle households owning vehicles with differences in fuel economy. Household switching is measured as a change in the fraction of miles driven in the higher efficiency vehicle, a distance-normalized measure of a household's relative reliance on their high efficiency vehicle on its randomly-assigned travel day. Reliance on the high efficiency vehicle could change by season or day of the week, for example, if weekend or summer driving required a roomier or better equipped vehicle. Variables to capture season and weekday or weekend variation in driving were included in the model.

1) Model Specification

I specify a model that is designed to quantify the relationship between changes in cost per mile savings and the fraction of miles (*milfrac*, a value between zero and one) traveled in the higher fuel economy vehicle (versus the household's alternative choice, designated the lower fuel economy vehicle), conditional on the decision to drive. The difference in cost per mile of driving the higher instead of the lower fuel economy vehicle, a function of the vehicle combination and the gasoline price (including state tax) that each household faces, was computed and included on the right-hand side of the equation as the primary independent variable of interest. Cost per mile is computed by dividing the gasoline price (dollars per gallon) by the vehicle's fuel economy (miles per gallon).

The effect of price per mile savings on changes in the fraction of miles driven in the more efficient vehicle will not be constant over the range of values between zero and one. Ordinary least squares (OLS) regression therefore will not provide the best estimates of the effect of interest, and predicted values using the OLS specification lie outside of the 0-1 interval (Papke & Wooldridge, 1993). In the present case in both the proposed model and in the observations a large number of zeros and ones are likely to occur because on their randomly assigned travel day, some households will use only one of their two vehicles, even if the second vehicle is used regularly. Following Papke and Wooldridge (1993), I use a limited dependent variable model with logit link to estimate the coefficient on per mile savings using quasi-likelihood methods, and include the predicted margins as well as marginal effects. The model shown in Equations (6) through (8) below was constructed to explicitly account for nonlinear behavior of the relationship between $milfrac_i$ and price per mile savings, and compared to the OLS estimates. Equations (6) and (7) show the form of the model with and without variables explicitly labeled. Equation (8) shows the logit link specification.

(6) $$E(y_i|x_i) = G(X_i\beta), 0 \leq G(z) \leq 1 \ \forall \ z \in R$$

(7) $$milfrac_i(0 < y < 1) = G(\beta_0 + \beta_1(savings_i) + \beta X_i + \epsilon_i)$$

(8) $$G(u) = \ln\left(\frac{u}{1-u}\right)$$

For the aggregate sample, the sensitivity of the coefficient on per mile cost savings ($savings_i$) to the inclusion of several covariates that may influence its magnitude was tested. The first is income. Households with higher incomes may be less sensitive to small changes in the cost of using particular vehicles, especially if the lower fuel economy vehicle offers improved comfort or performance. To account for the fact that households may use larger vehicles for a higher percentage of miles in the summer in the absence of a fuel price increase (for instance, for family road trips), I included seasonal dummy variables in the equation. Average household vehicle occupancy over all trips was also included to capture vehicle passenger capacity requirements. Household size was also added to control for additional factors that might affect the choice of a car, such as its likelihood of being in use and thus unavailable for any particular trip, limiting household switching ability. In order to facilitate interpretation of the β_1 estimates the predicted margins and marginal effects calculated.

2) Aggregate estimates of vehicle switching

Switching propensity was first estimated at the level of the aggregate two-vehicle sample and shown in **Table 6a**. The GLM estimates are shown in columns (1) through (6) and the OLS estimates are included for comparison on column (7). The marginal effects estimated with both the GLM and OLS models are included in **Table 6b**. In the GLM model, the marginal effect of an increase in per mile savings decreases with the magnitude of the savings. On average 1 cent increase in the per-mile cost savings raises the fraction of miles traveled in the higher fuel economy vehicle between 0.005-0.016. The average increase in per-mile cost savings was 3.5 cents, which would result in a modest but significant shift in the fraction of miles traveled in the high fuel economy vehicle by around 0.048. As expected the GLM estimates of marginal effect bracket the OLS estimate. The average fraction of miles driven in the high fuel economy vehicle for the two-vehicle sample was measured at 0.523. For the remainder of the analysis the GLM specification is used and only the predictive margins and marginal effects reported.[4]

3) Estimates of vehicle switching by income level

The propensity to switch vehicles strongly decreases with increasing income (**Table 7**). In addition to per mile cost savings, the covariates included in the model were seasonal dummy variables, household size, and a dummy for weekday driving. The marginal effect for the lowest income households ranges from 0.0245 to 0.0114 as the per mile savings increases, while the effect for highest income households is much lower, decreasing from 0.0062 to 0.0060. This result is consistent with higher income households placing less value on the switching opportunity, given that vehicle transportation costs (and any related cost savings) account for a

[4] The coefficient estimates for all covariates were not provided in order to save space but can be provided upon request.

smaller percentage of the household's budget. The second and third highest income categories fall in between these two extremes in terms of their switching propensity.

4) Estimates of vehicle switching by urbanization

Vehicle switching also seems to decrease with degree of urbanization (**Table 8**). The natural log of household income was added back to the model as an explanatory variable alongside seasonal dummy variables, household size, and a dummy for weekday driving. The marginal effect of a change from zero in price per mile savings is likely to increase the fraction of miles traveled in the more efficient vehicle by 0.0108 for urban households but more than twice as much for semi-urban (0.0263) and rural (0.0221) households. The reduced propensity of urban households to switch vehicles suggests that these households may be on average less able to reallocate use of their vehicles, perhaps because vehicle usage is already tightly optimized around necessary uses or because adult household members in urban areas require them for commuting to work.

C. The Relationship between Per Mile Cost Savings and the Choice of a High Efficiency Vehicle by Trip

The analysis of vehicle switching at the household level suggests a modest level of switching takes place at the level of the household, but does the probability of choosing the high efficiency vehicle for any particular trip actually increase? A trip is defined is any contiguous trip for which the same vehicle is used and for which a single decision of which vehicle to use is made. For example, a household cannot use one vehicle to drive to the grocery store and the other vehicle to drive home. Chained trips (contiguous trips often combining multiple purposes without returning home) are thus considered as a single trip. In this analysis the dependent variable is either 0 or 1, depending on whether the household assigned the high efficiency vehicle to a particular trip. Covariates included in the model include per mile savings, household size, average passengers per vehicle, and trip distance. The results are shown in **Table 9**. The estimates of the effect of price per mile savings appear to be stable and highly significant. On a per trip basis, the probability of choosing the high efficiency vehicle increases with per-mile cost savings. The log-odds ratio of choosing the high efficiency vehicle for a particular trip increases by 2.8-2.9% for each one cent increase in the savings associated with switching. Expressed as an odds ratio, the odds of choosing the high efficiency vehicle for a particular trip increase by 1.02 in response to a one cent in price per mile savings.

To investigate the possibility that switching may vary by trip purpose, I consider nine subcategories of trips grouped by the fact that part or all of a trip was dedicated to a particular task or function. The trip purposes considered include to/from work, work-related business, shopping, other family/personal business, school or church, medical or dental, vacation, visit friends or relatives, and other social or recreational trips. In addition to per mile cost savings, household size, average number of passengers, and trip distance were also included as covariates in the regression. The results are shown in **Table 10**. The coefficient on household size as a predictor of high efficiency vehicle choice is negative and significant for all trips except commuting to work and work-related business. Trip distance only modestly increased the odds of choosing the efficient vehicle (at a statistically significant level) for commute trips. Switching is most pronounced for trips involving daily functions such as commuting, shopping, medical or dental visits, and visiting friends and relatives, but not significant for vacation trips, where vehicle size, comfort, performance, or other attributes negatively correlated with fuel economy may offset the propensity to choose a vehicle with the lowest cost per mile. Moreover, since vacation trips account for only 1% of total trips and a relatively small fraction of total household mileage, the household may not have a strong rationale to prioritize the high fuel economy vehicle on these trips.

5. Conclusions and Extensions

A. Conclusions

Based on this analysis, households increase their relative reliance on higher efficiency vehicles when gasoline prices rise. This shifting occurs both in terms of the share of high efficiency vehicle use in household travel (a distance-normalized measure that accounts for fluctuations in total miles driven), and on a per trip basis.

Vehicle switching is likely to form part of any household response to an increase in fuel prices, whether mandated by policy or driven by fuel markets. The results presented here suggest that for the average two-vehicle household in our sample (with average fuel economy for the high efficiency vehicle equal to 22.69 and low efficiency vehicle equal to 17.51), a $2 increase in gasoline price assuming a base price of $2 per gallon would result in an increase of 5.21 cents per mile. This per mile savings would induce the household to increase the fraction of miles traveled in the more efficient vehicle by 0.0242. If the household does not reduce miles traveled, a household that drives an average of 25,000 vehicle miles per year will have saved 7.9 gallons of fuel, or $32. By contrast, complete switching would reduce fuel use by 155 gallons, or $622. Any reduction in vehicle-miles traveled means that the contribution to fuel use reduction from switching will be smaller still.

The modest size of the savings achieved by the household through switching may partially explain why the response seems to be most prevalent among low income households. The lower level of switching observed in urban areas could be influenced by the existence of more substitutes for vehicle transport (including public transit and carpooling), or simply the fact that urban households more tightly optimize the use of both vehicles (e.g. they have two commuters in the family).

On a per trip basis, the fact that switching occurs more readily for shorter non-discretionary trips such as commuting, shopping, or medical/dental visits suggests that frequency and contribution to overall mileage are important factors. Distance may constrain switching to the extent that low on-road fuel economy is correlated with attributes that increase in value with trip distance. Consistent with this hypothesis, switching does not seem to occur on vacation (generally longer-distance) trips. For these longer trips, comfort and performance may grow more important—to the extent that these attributes trade off with fuel efficiency to influence on-road fuel economy, it would reduce the household's propensity to choose its lower efficiency vehicle for longer trips.

By quantifying the role of vehicle switching, I have shown that its contribution to the overall household response to changes in the gasoline price is relatively modest. While complete switching (without reducing travel distance) would obviously produce greater savings, it may be difficult or even impossible depending on the characteristics of individual households. Understanding the factors that enable or constrain a household's ability to reduce fuel use will be important in identifying the distributional impacts of policies aimed at influencing fuel use and emissions from passenger vehicles in the United States.

B. Extensions

The analysis of the effect of per mile cost savings on switching could be usefully extended to households owning more than two vehicles, to investigate switching behavior, given that three-vehicle households appear to have more elastic VMT and gasoline demand responses to gasoline price increases. For households with more than two vehicles, a logit specification that accommodates multiple alternatives would be needed. Further conditioning on the type of vehicles owned could lend insight into the role of vehicle attributes in switching decisions.

This paper has estimated the magnitude of household vehicle switching propensity in the short run and has relied on model specifications that could mask any important discontinuities in consumer vehicle usage behavior. For instance, anecdotal reports that consumers left their hummers in the garage in favor of hybrids only when gasoline prices spiked above $4 would not be visible in the present analysis. Thus a study that considers the long run and includes finer resolution in gasoline price signals would help to pick up these potentially important nonlinear effects.

Finally, future work could use the same data to look at which households purchased new vehicles over the survey period and the relationship between gasoline price and the fuel economy of those vehicles, conditional on the attributes of vehicles the household already owns. Investigating the usage of these recently purchased vehicles during the summer of 2008 and into the fall of 2009 could help to shed light on the relationship between the fuel economy of preexisting household vehicles and the fuel economy of newly purchased vehicles.

6. References

AAA [American Automobile Association]. (2009). How much does it cost to drive? (http://www.aaaexchange.com/Assets/Files/200948913570.DrivingCosts2009.pdf).

Allcott, H. & Wozny, N. (2010). Gasoline prices, fuel economy, and the energy paradox. Cambridge, MA: Center for Economic and Environmental Policy Research. (http://web.mit.edu/ceepr/www/publications/workingpapers/2010-003.pdf).

An, F. & DeCicco, J. (2007). Trends in Technical Efficiency Trade-Offs for the U.S. Light Vehicle Fleet. SAE Technical Paper Series. Detroit, MI: SAE International.

Bento, A.M., Goulder, L.H., Jacobsen, M.R., & Haefen, R.H. (2009). *Distributional and efficiency impacts of increased U.S. gasoline taxes*. Ithaca, NY: Cornell University.

Brons, M., Nijkamp, P., Pels, E., & Rietveld, P. (2006). A meta-analysis of the price elasticity of gasoline demand. A system of equations approach. Rotterdam, Netherlands: Tinbergen Institute, Erasmus University

Dahl, C. & Sterner, T. (1991), Analyzing gasoline demand elasticities: A survey, *Energy Economics*, Vol. 13(3), pp 203-210.

EIA [Energy Information Agency]. (2010). Weekly retail gasoline and diesel prices. Washington, D.C.: Energy Information Agency, U.S. Department of Energy. (http://www.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm).

EPA [Environmental Protection Agency]. (2004). EPA's fuel economy and emissions programs. (http://www.epa.gov/fueleconomy/420f04053.htm).

Espey, M. (1996). Explaining the variation in elasticity estimates of gasoline demand in the United States: A meta-analysis. *Energy Journal*, 17(3), 49-60.

Feng, Y., Fullerton, D., & Gan, L. (2007), Car choices, miles driven, and pollution policies, Cambridge, MA: National Bureau of Economic Research.

FHWA (Federal Highway Administration). (2009a). National Household Transportation Survey. (http://www.fhwa.dot.gov/policy/ohpi/nhts/index.cfm)

FHWA [Federal Highway Administration]. (2009b). Monthly Motor Fuel Reported by State, 2008. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration. (http://www.fhwa.dot.gov/ohim/mmfr/dec08/dec08.pdf).

FHWA [Federal Highway Administration]. (2010). Monthly Motor Fuel Reported by State, 2009. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration. (http://www.fhwa.dot.gov/ohim/mmfr/dec09/dec09.pdf).

Goodwin, P. (1992). A review of new demand elasticities with special reference to short and long run effects of price changes, *Journal of Transport Economics and Policy*, 26, 155-163.

Graham, D.J. & Glaister, S. (2004). Road traffic demand elasticity estimates: A review. *24*(3), 261-274.

Hausman, J. (1979). Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables. *Bell Journal of Economics*, *10*(1), 33-54.

Hughes, J.E., Knittel, C.R., & Sperling, D. (2006). Evidence of a shift in the short-run price elasticity of gasoline demand. Cambridge, MA: National Bureau of Economic Research.

Klier, T. & Linn, J. (2008). The price of gasoline and the demand for fuel efficiency: Evidence from monthly new vehicle sales data (Working Paper No. 2009-15). Chicago, Illinois: Federal Reserve Bank of Chicago.

Knittel, C.R. (2009). *Automobiles on steroids: Product attribute trade-offs and technological progress in the automobile sector*. (Report No. UCD-ITS-RR-09-16). Davis, CA: University of California at Davis.

Papke, L.E. & Wooldridge, J.M. (1993). Econometric methods for fractional response variables with an application to 401(K) plan participation rates. Cambridge, MA: National Bureau of Economic Research

Small, K.A. & Van Dender, K. (2007). Fuel efficiency and motor vehicle travel: The declining rebound effect. *The Energy Journal*, *28*(1) (2007), 25-51.

Sallee, J. & Slemrod, J. (2010). *Car Notches* (draft). Cambridge, MA: Department of Economics. (http://econ-www.mit.edu/files/5522).

Train, K. (1985). Discount rates in consumers' energy-related decisions: A review of the literature. Energy, *10*(12), 1243-1253.

Ward's. (2008). '08 Model Car and Light Truck U.S. Specifications and Prices. Ward's Automotive Group, Penton Media.

Table 1 Summary of studies on the elasticity of demand for a) gasoline and b) VMT with respect to gasoline price.

a)

Study	Elasticity	Comments
Graham & Glaister, 2004	-0.25	Based on 377 estimates
Goodwin, 1992	-0.27	
Hughes et al., 2006	-0.034 to -0.077	2000-2006
Hughes et al., 2006	-0.21 to -0.34	1975-1980
Espey, 1998	-0.23	Median based on 300 prior estimates
Dahl & Sterner, 1991	-0.26	Based on 97 studies
Small & Van Dender, 2007	-0.0657	U.S. 1997-2001

b)

Study	Elasticity	Notes
Graham & Glaister, 2004	-0.15	Uses vehicle-miles traveled
Brons et al., 2006	-0.12	Uses miles-traveled per vehicle

Figure 1 The gasoline price trajectory during the years 2008 and 2009.

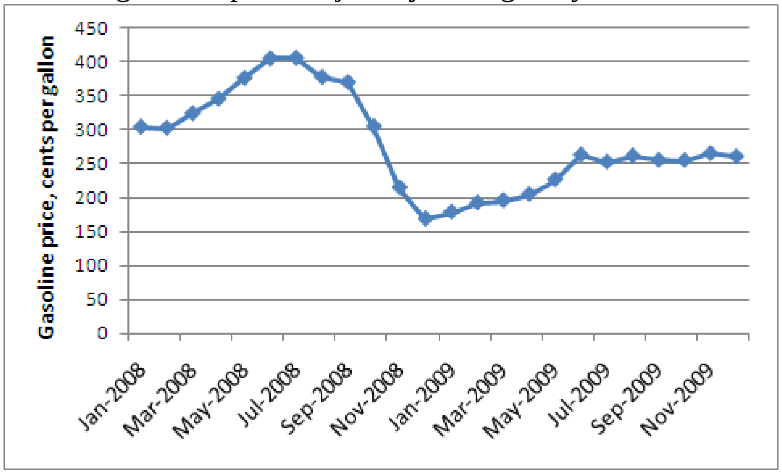

Figure 2 Distribution of household vehicle ownership in the United States.

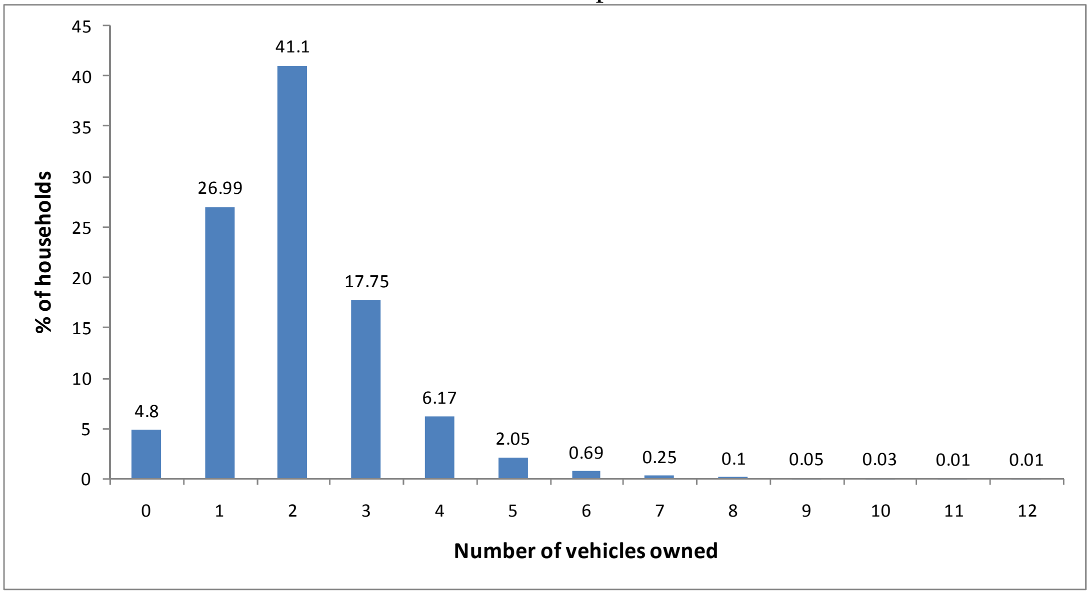

Table 2 Aggregate gasoline price elasticity of demand for VMT and gasoline. Log indicates natural log. (* p<0.05 ** p<0.01 *** p<0.001)

	Log VMT	**Log Gasoline Use**
Log gasoline price	-0.112***	-0.144***
	(-3.74)	(-4.88)
Log household income	0.316***	0.301***
	(39.08)	(37.69)
Spring	0.113***	0.142***
	(4.35)	(5.59)
Summer	0.135***	0.157***
	(5.23)	(6.16)
Fall	0.0491**	0.0681***
	(2.89)	(4.08)
Household size	0.251***	0.259***
	(63.87)	(67.05)
Weekday	-0.0942***	-0.0895***
	(-9.73)	(-9.41)
Constant	0.107	-2.645***
	(1.22)	(-30.56)
N	73321	73321

Table 3 Elasticities by income level. (* p<0.05 ** p<0.01 *** p<0.001)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	< $25,000/yr		**$25,000-$60,000/yr**		**$60,000-$100,000/yr**		**>$100,000/yr**	
	VMT	**Gasoline**	**VMT**	**Gasoline**	**VMT**	**Gasoline**	**VMT**	**Gasoline**
Log gasoline price	0.00436	-0.0354	-0.141**	-0.170***	-0.0993	-0.119*	-0.133*	-0.178**
	(0.05)	(-0.38)	(-2.76)	(-3.38)	(-1.76)	(-2.15)	(-2.33)	(-3.18)
Spring	0.108	0.131	0.0912*	0.126**	0.109*	0.133**	0.139**	0.172***
	(1.33)	(1.63)	(2.05)	(2.86)	(2.22)	(2.75)	(2.86)	(3.62)
Summer	0.0000312	0.0300	0.140**	0.159***	0.157**	0.173***	0.156**	0.185***
	(0.00)	(0.37)	(3.14)	(3.62)	(3.24)	(3.62)	(3.19)	(3.84)
Fall	-0.0340	-0.00789	0.0559	0.0733*	0.0358	0.0533	0.0895**	0.109***
	(-0.63)	(-0.15)	(1.91)	(2.54)	(1.13)	(1.73)	(2.79)	(3.47)
Household size	0.271***	0.276***	0.271***	0.279***	0.243***	0.252***	0.222***	0.234***
	(21.58)	(22.15)	(37.37)	(39.17)	(34.76)	(36.32)	(32.54)	(35.22)
Weekday	-0.0726*	-0.0682*	-0.0738***	-0.0686***	-0.0720***	-0.0682***	-0.150***	-0.145***
	(-2.47)	(-2.34)	(-4.45)	(-4.20)	(-3.91)	(-3.76)	(-8.15)	(-8.05)
Constant	3.044***	0.157*	3.447***	0.534***	3.654***	0.722***	3.892***	0.966***
	(45.41)	(2.38)	(91.49)	(14.37)	(87.27)	(17.47)	(92.51)	(23.47)
N	11709	11709	26697	26697	18395	18395	16520	16520

Table 4 Elasticities by degree of urbanization. (* p<0.05 ** p<0.01 *** p<0.001)

	(1)	(2)	(3)	(4)	(5)	(6)
	Urban		**Semi-urban**		**Rural**	
	VMT	Gasoline	VMT	Gasoline	VMT	Gasoline
Log gasoline price	-0.0916**	-0.130***	-0.0931	-0.106	-0.0642	-0.0781
	(-2.70)	(-3.89)	(-0.71)	(-0.83)	(-0.97)	(-1.21)
Log household income	0.357***	0.344***	0.337***	0.322***	0.259***	0.235***
	(38.00)	(37.05)	(10.12)	(9.91)	(15.47)	(14.18)
Spring	0.0775**	0.110***	0.0641	0.0676	0.0922	0.116*
	(2.63)	(3.81)	(0.57)	(0.62)	(1.65)	(2.13)
Summer	0.110***	0.136***	0.101	0.105	0.0880	0.0986
	(3.75)	(4.71)	(0.89)	(0.95)	(1.55)	(1.77)
Fall	0.0423*	0.0650***	0.0543	0.0601	0.0259	0.0351
	(2.22)	(3.47)	(0.71)	(0.80)	(0.68)	(0.93)
Household size	0.252***	0.263***	0.256***	0.253***	0.243***	0.245***
	(56.69)	(60.04)	(14.58)	(14.73)	(28.87)	(29.31)
Weekday	-0.0952***	-0.0879***	-0.105*	-0.107**	-0.0825***	-0.0860***
	(-8.66)	(-8.12)	(-2.52)	(-2.64)	(-3.88)	(-4.14)
Constant	-0.451***	-3.230***	-0.110	-2.831***	1.088***	-1.562***
	(-4.44)	(-32.16)	(-0.30)	(-7.88)	(5.97)	(-8.66)
N	53628	53628	4833	4833	14859	14859

Table 5 Gasoline price elasticity of demand for VMT and gasoline for a) one-vehicle, b) two-vehicle, and c) three-vehicle households. (* p<0.05 ** p<0.01 *** p<0.001)

	(1)	(2)	(3)	(4)	(5)	(6)
	One-vehicle households		**Two-vehicle households**		**Three-vehicle households**	
	VMT	**Gasoline**	**VMT**	**Gasoline**	**VMT**	**Gasoline**
Log gasoline price	-0.154*	-0.181**	-0.0865*	-0.115**	-0.192**	-0.230***
	(-2.35)	(-2.77)	(-2.05)	(-2.75)	(-2.89)	(-3.56)
Log household income	0.157***	0.135***	0.212***	0.192***	0.211***	0.191***
	(10.56)	(9.20)	(16.42)	(15.08)	(10.53)	(9.56)
Spring	0.157**	0.189***	0.100**	0.125***	0.129*	0.165**
	(2.78)	(3.37)	(2.72)	(3.44)	(2.28)	(3.00)
Summer	0.162**	0.184**	0.115**	0.126***	0.185**	0.224***
	(2.84)	(3.25)	(3.14)	(3.47)	(3.28)	(4.06)
Fall	0.0894*	0.111**	0.0537*	0.0679**	0.0789*	0.0999**
	(2.39)	(3.00)	(2.22)	(2.84)	(2.12)	(2.75)
Household size	0.255***	0.270***	0.196***	0.207***	0.181***	0.186***
	(21.26)	(23.01)	(31.41)	(33.44)	(22.27)	(22.97)
Weekday	-0.0325	-0.0295	-0.0932***	-0.0876***	-0.120***	-0.114***
	(-1.54)	(-1.41)	(-6.68)	(-6.38)	(-5.95)	(-5.76)
Constant	1.433***	-1.281***	1.385***	-1.310***	1.705***	-0.975***
	(8.87)	(-8.03)	(9.77)	(-9.37)	(7.63)	(-4.40)
N	19949	19949	32778	32778	13701	13701

Table 6 Effect of per mile cost savings on switching behavior in aggregate sample with a) GLM coefficients and z-statistics shown in columns (1) through (6) and OLS coefficients and statistics shown in (7) and b) predictive margins and marginal effects for the GLM model. S.E. – standard errors

a)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Per mile savings	0.0540***	0.0517***	0.0541***	0.0562***	0.0556***	0.0556***	0.0136***
	(11.68)	(10.83)	(10.52)	(10.94)	(10.77)	(10.78)	(11.00)
Log of household income		-0.176***	-0.177***	-0.142***	-0.151***	-0.151***	-0.0371***
		(-6.57)	(-6.58)	(-5.20)	(-5.53)	(-5.53)	(-5.58)
Spring			-0.0234	-0.0282	-0.0280	-0.0283	-0.00694
			(-0.61)	(-0.74)	(-0.74)	(-0.75)	(-0.74)
Summer			-0.0537	-0.0659	-0.0523	-0.0514	-0.0126
			(-1.34)	(-1.64)	(-1.31)	(-1.28)	(-1.27)
Fall			0.000494	-0.00581	-0.00306	-0.00270	-0.000568
			(0.01)	(-0.16)	(-0.09)	(-0.08)	(-0.06)
Household size				-0.104***	-0.0488***	-0.0482***	-0.0119***
				(-8.84)	(-3.69)	(-3.64)	(-3.66)
Average passengers per vehicle					-0.140***	-0.141***	-0.0347***
					(-7.00)	(-7.06)	(-7.17)
Weekday						-0.0251	-0.00611
						(-0.84)	(-0.83)
Constant	-0.0954***	1.857***	1.870***	1.784***	1.992***	2.012***	0.994***
	(-4.69)	(6.22)	(6.24)	(5.95)	(6.60)	(6.66)	(13.55)
N	17965	16766	16766	16766	16766	16766	16766

b)

savings	**Predicted *milfrac***		**Marginal effect (*milfrac*|*savings*)**	
(cents per mile)	**Estimate**	**S.E.**	**Estimate**	**S.E.**
0	0.474555	0.005482	0.013734	0.001262
2.5	0.508954	0.003452	0.013764	0.001278
5	0.543266	0.003718	0.013665	0.001259
7	0.577173	0.0059	0.01344	0.001205
10	0.61037	0.008479	0.013099	0.00112
15	0.673561	0.013241	0.012117	0.00088
20	0.731053	0.016796	0.010843	0.000589

Table 7 Predictive margins and marginal effects of per mile savings on fraction of miles traveled in higher efficiency vehicle by income category. S.E. – standard errors

	Predicted *milfrac*		**Marginal effect**	
Income <$25,000				
Per mile savings (cents)	**E(*milfrac*|X$\boldsymbol{\beta}$)** $A = \pi r^2$**)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4767	0.0221	0.0245	0.0049
2.5	0.5379	0.0135	0.0244	0.0050
5	0.5980	0.0135	0.0236	0.0047
7	0.6553	0.0207	0.0222	0.0040
10	0.7084	0.0282	0.0203	0.0031
15	0.7989	0.0376	0.0158	0.0012
20	0.8667	0.0386	0.0114	0.0006
Income $25,000 - $60,000				
Per mile savings (cents)	**E(*milfrac*|X$\boldsymbol{\beta}$)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4706	0.0098	0.0221	0.0023
2.5	0.5259	0.0061	0.0221	0.0023
5	0.5805	0.0066	0.0216	0.0022
7	0.6332	0.0102	0.0206	0.0020
10	0.6829	0.0140	0.0192	0.0016
15	0.7703	0.0194	0.0157	0.0008
20	0.8394	0.0210	0.0120	0.0002
Income $60,000 - $100,000				
Per mile savings (cents)	**E(*milfrac*|X$\boldsymbol{\beta}$)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4809	0.0100	0.0102	0.0023
2.5	0.5063	0.0062	0.0102	0.0023
5	0.5318	0.0067	0.0101	0.0023
7	0.5570	0.0109	0.0101	0.0023
10	0.5820	0.0159	0.0099	0.0022
15	0.6306	0.0257	0.0095	0.0019
20	0.6767	0.0343	0.0089	0.0016
Income >$100,000				
Per mile savings (cents)	**E(*milfrac*|X$\boldsymbol{\beta}$)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4678	0.0095	0.0062	0.0022
2.5	0.4834	0.0061	0.0062	0.0022
5	0.4989	0.0068	0.0062	0.0022
7	0.5144	0.0109	0.0062	0.0022
10	0.5300	0.0159	0.0062	0.0022
15	0.5608	0.0264	0.0061	0.0021
20	0.5911	0.0366	0.0060	0.0020

Table 8 Predictive margins and marginal effects of per mile savings on fraction of miles traveled in higher efficiency vehicle by degree of urbanization. S.E. – standard errors

	Predicted *milfrac*		**Marginal effect**	
Urban				
Per mile savings (cents)	**E(*milfrac*|X*β*)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4772	0.0062	0.0108	0.0014
2.5	0.5041	0.0039	0.0108	0.0015
5	0.5311	0.0043	0.0107	0.0014
7	0.5578	0.0069	0.0106	0.0014
10	0.5843	0.0099	0.0105	0.0014
15	0.6356	0.0160	0.0100	0.0012
20	0.6840	0.0211	0.0093	0.0009
Semi-urban				
Per mile savings (cents)	**E(*milfrac*|X*β*)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4373	0.0236	0.0263	0.0054
2.5	0.5037	0.0146	0.0267	0.0057
5	0.5699	0.0157	0.0262	0.0055
7	0.6337	0.0247	0.0248	0.0047
10	0.6932	0.0337	0.0227	0.0036
15	0.7941	0.0440	0.0175	0.0012
20	0.8681	0.0437	0.0123	0.0009
Rural				
Per mile savings (cents)	**E(*milfrac*|X*β*)**	**S.E.**	**(*milfrac*|*savings*)**	**S.E.**
0	0.4736	0.0131	0.0221	0.0029
2.5	0.5290	0.0081	0.0221	0.0030
5	0.5836	0.0083	0.0216	0.0029
7	0.6363	0.0128	0.0205	0.0025
10	0.6860	0.0178	0.0191	0.0021
15	0.7730	0.0246	0.0156	0.0010
20	0.8415	0.0266	0.0119	0.0002

Table 9 Effect of price per mile on the choice of a high efficiency vehicle by trip for the aggregate sample.

	(1)	(2)	(3)	(4)
Per mile savings	0.0280***	0.0285***	0.0284***	0.0286***
	(9.88)	(10.06)	(10.02)	(10.08)
Household size		-0.0769***	-0.0711***	-0.0703***
		(-11.24)	(-10.10)	(-9.97)
Average passengers			-0.0735***	-0.0962***
			(-3.52)	(-4.20)
Trip distance (miles)				0.000222*
				(2.41)
_cons	0.0209	0.228***	0.346***	0.375***
	(1.79)	(10.46)	(8.65)	(8.99)
N	64563	64563	64563	64563

Table 10 The effect of per-mile cost savings by trip purpose.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	To / From Work	**Work-related business**	**Shopping**	**Other family / personal business**	**School / church**	**Medical / dental**	**Vacation**	**Visit friends / relatives**	**Other social / recreation**
Per mile savings	0.0330***	0.0220	0.0366***	0.0306***	0.0332***	0.0471***	-0.0206	0.0424***	0.0344***
	(6.21)	(1.73)	(8.50)	(6.46)	(4.29)	(4.59)	(-1.07)	(4.98)	(7.50)
Household size	0.0155	0.0808**	-0.103***	-0.0942***	-0.175***	-0.114***	-0.170**	-0.160***	-0.110***
	(1.20)	(2.62)	(-9.15)	(-8.46)	(-10.17)	(-4.12)	(-3.27)	(-7.49)	(-9.24)
Average passengers	-0.00573	0.0299	-0.0829**	-0.0933**	-0.0334	-0.0740	-0.0710	-0.0614	-0.109**
	(-0.10)	(0.32)	(-2.61)	(-2.61)	(-0.56)	(-0.82)	(-0.87)	(-1.19)	(-3.28)
Trip distance (miles)	0.00151***	0.000697	0.0000884	0.000367	-0.0000493	0.00158**	-0.000158	0.000376	0.000191
	(4.36)	(1.49)	(0.67)	(1.94)	(-0.14)	(2.97)	(-0.81)	(1.85)	(1.37)
Constant	-0.0934	-0.391*	0.415***	0.447***	0.667***	0.406**	0.652***	0.539***	0.526***
	(-0.90)	(-2.07)	(7.21)	(6.87)	(6.15)	(2.59)	(3.34)	(5.50)	(8.63)
N	19077	3218	27929	23774	9099	5055	1302	7535	24060