

Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically-Based Multi-Market Study

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I. Introduction

For several reasons, reducing gasoline consumption from automobiles is a major U.S. public policy issue. Reduced gasoline consumption can produce benefits in terms of national security by reducing dependence on imported crude oil. In addition, lower gasoline use confers environmental benefits: reduced emissions of CO₂ (the principal anthropogenically sourced “greenhouse gas” associated with global climate change) and lower emissions of other pollutants associated with local health effects.

Recently, many analysts have called for new or more stringent policies to discourage gasoline consumption. Proposals include a tightening of corporate average fuel economy (CAFE) standards, subsidies to retirements of older (gas-guzzling) vehicles, as well as increments to the federal gasoline tax. This paper examines the gas-tax option, employing an econometrically based multi-market simulation model to explore the policy’s efficiency and distributional implications.

This study differs from earlier work in several ways. Several prior studies have investigated gasoline consumption either by employing a demand function for gasoline or by deriving this demand from households’ vehicle-miles traveled (VMT).¹ In these studies, the composition of the automobile fleet is taken as fixed. One would expect a gasoline tax to influence the composition of the vehicle fleet (e.g., the market share of more fuel-efficient cars) as well as the amount of driving. The model employed in this study allows for both impacts.

As in Goldberg (1995), Berry, Levinson, and Pakes (1995), and Petrin (2002), we account for the imperfectly competitive nature of the new-car market. However, in contrast with these studies we consider interactions between the markets for new, used, and scrapped cars.² The impacts of a gasoline tax can importantly depend on such interactions. Higher gasoline taxes could stimulate higher rates of scrappage of older, fuel-inefficient cars, and could also

¹Schmalensee and Stoker (1999) use household-level data on gasoline consumption to arrive at an estimate of the income and price elasticity of demand for gasoline. In contrast, Berkovec (1985), Mannering and Winston (1985), Train (1986), and West (2004) sequentially estimate automobile ownership and VMT decisions using discrete choice and linear regression techniques. These studies derive the elasticity of demand for gasoline from the VMT elasticity and the fuel economy of the different vehicles. Poterba (1991) generates elasticities of demand for gasoline use by transforming Train’s estimates of elasticities for VMT.

²Berkovec (1985) develops a model with interactions among these markets. His model assumes pure competition among auto producers, however.

promote shifts in demand from used cars to especially fuel-efficient new cars. Studies that ignore these adjustments could understate a gas tax's impacts on fuel consumption.

Another set of differences from earlier work is in the econometric approach. By allowing the structural parameters entering preferences to vary randomly across households, we are able to account for rich patterns of unobserved preference heterogeneity. In addition, in contrast with nearly all prior work, we adopt an estimation approach that simultaneously estimates in a utility-consistent manner each household's automobile choice and its choice of VMT.³ This is important for addressing the welfare impacts of policies.⁴

We consider the welfare impacts both in the aggregate (overall utility-based efficiency costs) as well as in terms of their distribution across households distinguished by income, car ownership, and size of household. Simulation results show that whether a gas tax increase is regressive in its impact depends on the manner in which revenues from the tax are recycled (returned) to the economy. The results also reveal significant heterogeneity in welfare impacts within household income groups. These results highlight the importance of accounting for household heterogeneity in tastes and car-ownership in evaluating distributional impacts.

II. Structure of the Simulation Model

We sketch the simulation model's structure here. Details are provided in an appendix to this paper, available on request.

A. Household Demands

Households obtain utility from car ownership and use, as well as from consumption of other commodities. The utility enjoyed from driving depends on characteristics of the automobile, as well as the amount of driving (vehicle-miles traveled). The decision whether to

³ A recent working paper by Feng, Fullerton, and Gan (2004) offers one approach to integrating the purchase and vehicle-use decisions. The present study also confronts the consistency issue, but employs a different approach that accommodates a much larger number of automobiles.

⁴ Prior studies have tended to focus on policies' impacts on prices or quantities, rather than the welfare consequences. For example, Goldberg (1998) studies the impacts of tightening of CAFE standards on the composition of vehicle fleet.

own a car is integrated with the decision about VMT. Each household has exogenous income; most households also are endowed with cars. If a household has a car endowment, it chooses whether to hold or relinquish (sell or scrap) that car; if it relinquishes the car it also decides whether to purchase a different car (new or used). If a household does not have a car endowment, it chooses whether to purchase a car.

The number of distinct car types is very large: currently there are several thousand types of new and used cars and trucks in operation. In addition, many U.S. households hold more than one automobile. Together these features imply a huge number of possible household car choices, far more than would be tractable econometrically or in a simulation model. To achieve manageable dimensionality, we organize distinct cars and trucks into 284 composite automobile categories based on a car's age, class, and manufacturer. In addition, to deal with multiple-car households, we adopt a variation of the repeated discrete-continuous modeling approach of Hendel (1999) and Dube (2004).⁵ Here we assume that household automobile choices arise from decisions made on T separable choice occasions where T is proportional to the number of adults in the household. On each choice occasion, the household makes a discrete choice of whether to choose one of the 284 composite cars. If the j^{th} automobile is chosen, the household then makes a continuous choice of VMT for the automobile. This discrete-continuous process is repeated across multiple choice occasions. A key attraction of this approach is that it significantly limits the dimensionality of the choice problem. The disadvantage is that it implicitly assumes that the household's automobile decisions with respect to different cars in its fleet are separable from each other.⁶

More concretely, we assume that household preferences on the t^{th} choice occasion ($t=1, \dots, T$) for the j^{th} automobile ($j=1, \dots, J$) can be represented by the conditional indirect utility function $U_{ij} = V_j(y/T - r_j, u_j, \mathbf{q}_j, \mathbf{z}, \boldsymbol{\beta}) + \varepsilon_{ij}$, where y is household income, r_j , u_j , and \mathbf{q}_j are automobile j 's one-year rental price, per-mile utilization price (i.e., operating cost), and non-

⁵ Most previous studies have avoided the difficulties arising with multiple car households by considering single car purchases in the new car market (e.g., Goldberg (1995), Berry, Levinsohn, and Pakes (1995) or by focusing on the roughly 85 percent of households with two or fewer cars (West (2004)).

⁶ Work in progress adopts an alternative approach, broadly similar to that in Feng, Fullerton, and Gan (2004), in which households choose alternative automobile bundles. This alternative approach has the advantage of permitting greater interdependencies among a household's automobile choices. Its main drawback is that it requires a more substantial degree of automobile aggregation as well as restrictions on the number of cars that households can choose to keep the dimensionality of the consumer's choice set tractable. In our work in progress, we aggregate automobiles into 18 composite categories and limit the number of cars that households can choose to no more than two to keep the number of automobile bundles manageable.

price characteristics, respectively. The vector \mathbf{z} contains household's characteristics, $\boldsymbol{\beta}$ is a parameter vector that varies randomly across households, and ε_{ij} represents additional unobserved heterogeneity that varies across households, automobiles, and choice occasions. Similarly, if the household chooses not to rent an automobile (i.e., chooses auto 0), her preferences can be represented by $U_{i0} = V_0(y/T, \mathbf{z}, \boldsymbol{\beta}) + \varepsilon_{i0}$. The rational household chooses the alternative that maximizes its utility. Assuming that each ε_{ij} is an independent draw from the type I extreme value distribution with common scale parameter μ , the probability that the household chooses the j^{th} automobile conditional on $\boldsymbol{\beta}$ is:

$$(1) \quad \Pr_i(j) = \frac{\exp(V_j / \mu)}{\sum_{k=0}^J \exp(V_k / \mu)}.$$

Because we employ a theoretically consistent preference specification, we can use Roy's identity to derive the conditional VMT demand for automobile j :

$$(2) \quad VMT_{ij} = -\frac{\partial U_{ij} / \partial u_j}{\partial U_{ij} / \partial (y/T)} = VMT_j(y/T - r_j, u_j, \mathbf{q}_j, \mathbf{z}, \boldsymbol{\beta}).$$

B. Supply of New and Used Cars

The model distinguishes five age categories, ten car classes, and seven manufacturer (make) categories.⁷ This yields 350 possible age-class-manufacturer combinations, but since some combinations are not realized the model actually includes 284 cars.

Each of the seven producers sets prices for its fleet of automobiles to maximize profits, given the prices set by its competitors. Thus we assume Bertrand competition. New cars differ by class and manufacturer. Let k index a given producer. Let Φ represent the set of all new cars and let $\Phi_k \subset \Phi$ represent the n_k new cars manufactured by producer k . The profit-maximization problem for producer k is

⁷ The age categories are less than 1 (new), 1-2, 3-6, 7-11, and 12-19 years old. The car classes are compact, luxury compact, midsize, fullsize, luxury midsize/fullsize, small SUV, large SUV, small truck, large truck, and minivan. The manufacturer categories are Ford, Chrysler-Daimler, General Motors, Honda, Toyota, other East Asian, and European.

$$(3) \quad \max_{\{p_j\}} \sum_{j \in \Phi_k} (p_j - c_j) \cdot q_j(\mathbf{p})$$

$$\text{subject to } \sum_{j \in T} q_j(\mathbf{p}) \cdot (e_j - \bar{e}_T) \geq 0 \quad \text{and} \quad \sum_{j \in C} q_j(\mathbf{p}) \cdot (e_j - \bar{e}_C) \geq 0$$

where p_j , c_j , and q_j are the price, marginal cost, and quantity demanded of car j (which is made by firm k). Marginal cost (c) is exogenous and assumed to be constant. \mathbf{p} denotes the vector of *all* new car prices. The two constraints in (3) above acknowledge the presence of CAFE standards.⁸ Above, \bar{e}_T and \bar{e}_C refer to the fuel-economy (miles per gallon) requirements for light trucks and passenger cars, respectively, and e_j refers to the fuel-economy of car j . Thus, the two constraints express the requirement that the given manufacturer achieve fleet-wide average fuel-economy above \bar{e}_T and \bar{e}_C , respectively, for the light trucks and cars it produces. To obtain the equilibrium under Bertrand competition, all car prices (and associated markups) must be solved for simultaneously. The appendix describes the solution method.

The used-car market equates the supply of cars (net of scrappage) with the demand for used cars. The stock of used cars is equal to an exogenously specified maximal amount, less the number of scrapped cars. The amount of scrappage is endogenous. As indicated in the appendix, for each car type, there is a probability distribution for maintenance costs. If a household owns a car requiring exceptionally high maintenance, it will prefer to scrap the car rather than pay the costs of keeping the car in operation. Higher gasoline taxes can induce higher rates of scrappage by raising the combined cost of ownership (maintenance plus fuel costs). This impact is particularly large for very old cars that have very low fuel-economy.

In general, each car type, or age-class-manufacturer combination, has its own market price. The model determines the set of prices for all car types that is consistent with each new-car producer's profit-maximization (first-order) conditions and that clears the used-car market, that is, causes every used car to be sold. Since the demand for every car depends on the prices of all other cars (new and used), all car prices need to be solved for simultaneously. The appendix details the solution method.

⁸ Some manufacturers elect to pay a fine rather than meet the constraint. In future work we will incorporate this option, which involves very minor changes to the objective function and solution procedure.

III. Data and Econometric Estimation

We estimated the parameters entering household preferences for automobile demand with the 2001 *National Household Travel Survey (NHTS)*, the most recent and comprehensive survey of U.S. automobile demand. The *NHTS* contains a cross-section of households' complete automobile holdings and VMT demands as well as relevant economic, demographic, and geographic data. We augment this information with data on car characteristics (e.g., weight, horsepower, wheelbase, and fuel-efficiency) that influence car choices. These data were obtained from *Ward's Automotive Yearbooks*, the *National Automotive Dealers' Association's Used Car Guides*, and the *EPA/DOE's fueleconomy.org* web site. Other sources (see appendix) offered data on operating costs (insurance fees, registration fees, and local gasoline prices and taxes).

In arriving at an estimation approach for this study, two issues were especially important. First, in order to generate meaningful assessments of welfare impacts, we wanted to simultaneously estimate the household's choice of VMT and car type in theoretically consistent way. Previous studies (e.g., Goldberg (1998), West (2004)) have employed two step-estimation strategies that do not integrate a household's car choice and its VMT demand decision in a manner fully consistent with utility maximization. Second, we were concerned about unobserved preference heterogeneity, which has the potential to bias our parameter estimates and yield implausible predictions about substitution patterns.

To address these concerns, we have developed a random-coefficient repeated discrete-continuous model that permits simultaneous estimation of each household's car and VMT choices. As discussed in Train (2003), random-coefficient specifications can generate more plausible structures of substitution relative to fixed parameter models, and modern simulation-based techniques have been developed in recent years to make the estimation of these models computationally feasible. In our application, we estimate our random-coefficient model within a Bayesian framework, using a variation of Allenby and Lenk's (1994) Gibbs Sampling algorithm. As indicated by the Bernstein-von Mises theorem, the posterior mean Bayesian estimates are asymptotically equivalent to maximum likelihood estimates. For us the Gibbs sampler is

particularly attractive because it is much less burdensome computationally than maximum simulated likelihood techniques.

To allow for additional preference heterogeneity across household types (i.e., married or single, working or retired, with or without children), we grouped the *NHTS* sample into 12 different strata and estimated separate parameters for each. Although too numerous to report here, the posterior means of our parameter estimates were generally consistent with our *a priori* expectations and suggested posterior mean VMT operating cost and income elasticities on the order of -0.70 and 0.64, respectively. We also found mean automobile holding elasticities with respect to the own rental price of roughly -0.75 for all cars and trucks and -1.78 for new cars and trucks.

IV. Results

We simulate the impact of raising the federal gasoline tax by 10, 30, or 50 cents per gallon. The benchmark gross-of-tax price of gasoline (which varies by state) averages around \$1.45,⁹ so the gas tax increments imply relative price increases between 6 and 35 percent. We examine various overall efficiency costs, other aggregate impacts (changes in fuel consumption and in average VMT), changes in the composition of the vehicle fleet, and distributional impacts across various household groups. We explore two types of revenue-recycling: “tax-based recycling,” in which revenues are recycled to households in proportion to their gasoline tax payments, and “income-based recycling,” where revenues are recycled in proportion to their benchmark income.

A. Gross Efficiency Costs and Changes in Gasoline Consumption

Table 1 indicates impacts on efficiency and aggregate gasoline use, as well as underlying changes in average VMT, average fuel-efficiency, and fleet-composition. The (gross) efficiency costs, expressed by the negative of the equivalent variation (EV), are about \$12, \$38, and \$68 per household for gas tax increases of 10, 30, and 50 cents, respectively. The efficiency costs are gross in that they take no account of environmental and other external benefits from the policy

⁹ This includes 18.5 cents in federal gasoline taxes and (on average) 23 cents in state taxes.

change. The corresponding average excess burdens (efficiency cost divided by taxes collected) are 0.15, 0.17, and 0.19. The size of this burden is not significantly influenced by the type of revenue-recycling. About 70 percent of the cost occurs as deadweight loss in the gasoline market, as implied by the wedge between producer and consumer prices of gasoline over the induced change in gasoline consumption. Other efficiency costs stem from the tax's impact on the level and composition of new-car production.

From the table, the implied (short-run) elasticity of demand for gasoline use is about -0.27. The gasoline tax increase induces a reduction in fleet size (increase in scrappage), a decline in quantity demanded of new cars relative to used cars, and a relative increase in quantity demanded of more fuel-efficient cars. The fleet-composition effects are very small. Over 95 percent of the reduction in gasoline consumption derives from reduced VMT, rather than from increases in average fuel-efficiency from changes in fleet composition. One reason for the small fleet-composition change is that these simulations only consider the impacts in the first year following a policy's implementation. Thus the effects through changes in the new-car market are muted. Work in progress examines impacts over the longer term.¹⁰

B. Distributional Impacts

Table 2 displays the distributional impacts of a 30-cent gas tax increase for various types of households, where households are grouped by income, family size (measured by the number of children) and stage of life (retired or not). The welfare impact (EV) of the policy is reported as a percentage of benchmark income. Under tax-based recycling, the gasoline tax increase is close to proportional in its impact.¹¹ The cost of policy for households with annual income less than \$25,000 is about 0.10% of their income, while for households with income greater than \$75,000 it is about 0.09%. Our results indicate that the cost of the policy relative to income is

¹⁰ A second reason reflects interactions between the gasoline tax and pre-existing CAFE standards. To the extent that the standards for cars and trucks are binding prior to the gas-tax increase, raising the gas tax induces no further improvement in the average fuel-economy of new cars or trucks. Fuel-economy improvements occur only through increases in the number of new cars relative to new trucks. In the absence of a CAFE standard, a fuel-economy improvement also occurs within the car and truck categories. This occurs when we perform a counterfactual simulation in which there is no pre-existing CAFE standard in place.

¹¹ It would be exactly proportional in the absence of relative price changes. Such changes differentially affect the values of household endowments and the commodities (cars) they prefer to purchase, thus causing slight departures from proportionality.

highest for households not retired and with children. As indicated in the table, these households tend to drive more than others.

The results under income-based recycling are very different. Here the impacts are highly regressive. Under income-based recycling, relatively low (high) income households enjoy much lower (higher) transfers than they do under tax-based recycling. For households with incomes below \$50,000 the cost of the policy is roughly twice as large under income-based recycling. Correspondingly, households earning over \$75,000 a year enjoy a welfare gain from the policy change.

Income-based recycling is relatively beneficial to households that do little driving, since these households nevertheless can enjoy significant recycled gas-tax revenues. Thus the retired suffer welfare losses under tax-based recycling, but enjoy welfare gains under income-based recycling. Similarly, while all car owners experience welfare losses under tax-based recycling, only the high-probability car owners¹² lose under income-based recycling. The presence or absence of car-ownership is especially significant for the poorest households. Indeed, these results suggest that there is considerable heterogeneity in the impacts of a gas tax on the poorest households: among these households, the impacts depend importantly on the nature of recycling, whether the household is retired, and presence or absence of car-ownership.

V. Conclusions

This paper describes and applies an econometrically estimated multi-market simulation model for analyzing policies to reduce automobile-related gasoline consumption. The estimation of household choices attends to observed and unobserved household heterogeneity (allowing for unusually rich distributional assessments), and consistently links household driving and car-purchase decisions. The simulation model considers interactions among the new-car, used-car, and scrap markets. It also addresses interactions between new policy initiatives and pre-existing regulations such as CAFE standards.

¹² In the model, every household has some positive probability of purchasing or retaining a car. High-probability car owners here are defined as households for which the probability of purchasing or retaining a car exceeds 25 percent per choice occasion (number of adult members + 1).

Simulation results indicate that gasoline tax increases of 10, 30, and 50 cents imply excess burdens of 15 to 19 cents per dollar of additional tax revenue. The excess burden is similar under the two types of revenue-recycling we consider. On the other hand, the two recycling methods have very different distributional consequences, including very different effects on households within given income classes.

We plan to improve the model in several ways and to perform other applications. The present model only considers a policy's impacts only in the year of its implementation. We are in the process of expanding the model to enable it to examine long-run effects associated with the gradual evolution of the automobile fleet. We also would like to explore alternative ways (including alternatives to our "choice-occasion" framework) to deal with the potentially very high dimensionality that arises from the multitude of car types and car combinations. In subsequent applications we hope to perform a more comprehensive assessment of distributional impacts, considering other demographic dimensions such as race and region of residence. We would also like to consider other policies to reduce gasoline consumption, including changes to CAFE standards and subsidies to retirements of low-mileage vehicles.

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Table 1 -- Economy-Wide Impacts of Gas Tax Increases¹

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	Base	1	2	3	4	5	6
Gas Tax Increase (\$)		\$0.10	\$0.30	\$0.50	\$0.10	\$0.30	\$0.50
Revenue Recycling		Tax- Based	Tax- Based	Tax- Based	Income- Based	Income- Based	Income- Based
Avg EV (\$)		-\$11.55	-\$38.00	-\$68.28	-\$11.77	-\$37.49	-\$67.48
Total EV / Gallons Avoided		-\$0.78	-\$0.88	-\$0.98	-\$0.73	-\$0.79	-\$0.86
Avg Gas Tax Payment		\$77.97	\$225.40	\$362.28	\$77.83	\$224.19	\$358.09
Avg Excess Burden		0.148	0.169	0.188	0.151	0.167	0.188
Avg Gas Consumption (gals)	794.5	-1.86%	-5.43%	-8.80%	-2.03%	-5.94%	-9.86%
Avg VMT (000's)	19.2	-1.82%	-5.33%	-8.63%	-1.99%	-5.82%	-9.64%
Avg MPG (VMT Weighted)	24.2	0.04%	0.11%	0.18%	0.05%	0.13%	0.24%
Fleet Size (000's)							
All Cars	44814.4	-0.17%	-0.52%	-0.85%	-0.18%	-0.52%	-1.02%
New Cars	3845.0	-0.53%	-1.55%	-2.52%	-0.56%	-1.65%	-2.38%
Used Cars	40969.4	-0.14%	-0.42%	-0.69%	-0.14%	-0.41%	-0.89%
High MPG Cars ²	27027.4	-0.15%	-0.45%	-0.74%	-0.15%	-0.44%	-0.84%
Low MPG Cars	17787.0	-0.21%	-0.63%	-1.03%	-0.21%	-0.63%	-1.29%

Table 2 -- Distributional Impacts of Gas Tax Increases (For \$0.30 Increase)

Income (000's)	Tax-Based Recycling						Income (000's)	Income-Based Recycling					
	All Households	Retired	Not Retired, No Children	Not Retired, Children	High Prob. Car Owner	Low Prob. Car Owner		All Households	Retired	Not Retired, No Children	Not Retired, Children	High Prob. Car Owner	Low Prob. Car Owner
	EV (% of Base Income)							EV (% of Base Income)					
<25	-0.103%	-0.093%	-0.104%	-0.119%	-0.110%	-0.084%	<25	-0.216%	0.033%	-0.311%	-0.482%	-0.429%	0.356%
25-50	-0.108%	-0.105%	-0.105%	-0.113%	-0.110%	-0.089%	25-50	-0.205%	0.038%	-0.164%	-0.403%	-0.281%	0.393%
50-75	-0.098%	-0.089%	-0.103%	-0.099%	-0.098%	-0.099%	50-75	-0.077%	0.132%	-0.116%	-0.113%	-0.102%	0.360%
>75	-0.092%	-0.094%	-0.092%	-0.091%	-0.092%	-0.091%	>75	0.079%	0.189%	0.093%	0.046%	0.063%	0.368%
	% Change in VMT							% Change in VMT					
<25	-5.43%	-4.87%	-5.45%	-6.39%	-5.48%	-5.31%	<25	-5.42%	-4.74%	-5.49%	-6.50%	-5.56%	-5.05%
25-50	-5.69%	-5.70%	-5.60%	-5.78%	-5.61%	-6.29%	25-50	-5.75%	-5.59%	-5.63%	-5.99%	-5.73%	-5.91%
50-75	-5.59%	-5.42%	-5.69%	-5.58%	-5.53%	-6.59%	50-75	-5.67%	-5.33%	-5.77%	-5.70%	-5.63%	-6.20%
>75	-5.35%	-5.70%	-5.11%	-5.49%	-5.24%	-7.38%	>75	-5.23%	-5.36%	-5.00%	-5.40%	-5.14%	-6.81%

Base Case (Predicted Values)

Income (000's)	All Households	Retired	Not Retired, No Children	Not Retired, Children	High Prob. Car Owner	Low Prob. Car Owner
	VMT (Thousand Miles)					
<25	10.1	6.4	11.1	14.9	13.3	1.5
25-50	20.9	13.3	19.7	27.0	23.1	3.3
50-75	27.9	18.6	29.3	29.8	29.2	6.6
>75	33.7	26.5	31.4	37.1	35.0	11.5
	Average MPG					
<25	25.46	25.44	25.83	24.81	25.24	26.05
25-50	24.70	24.79	25.08	24.22	24.61	25.45
50-75	24.57	24.72	24.93	24.32	24.52	25.42
>75	24.45	24.31	24.67	24.28	24.42	24.93