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

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I. Introduction

Because of its potential to improve the environment and enhance national security, reducing automobile-related gasoline consumption has become a major U.S. public policy issue. 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] These studies treat the composition of the automobile fleet as fixed. However, a gasoline tax can be expected to influence the fleet-composition (e.g., the market share of more fuel-efficient cars) as well as the amount of driving. 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 promote shifts in demand from used cars to especially fuel-efficient

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[1]Schmalensee and Stoker (1999) and West and Williams (2004) use household-level data on gasoline consumption to estimate 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.

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

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 can account for rich patterns of unobserved preference heterogeneity. And 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 evaluating welfare impacts.[4]

An appendix to this paper, available at www.stanford.edu/~goulder/gastaxpaper, details the simulation model's structure, data, estimation approach, and solution method.

We examine policy impacts both in the aggregate as well as across households distinguished by income, car ownership, and other characteristics. Simulation results show that whether a gas tax increase is regressive in its impact depends on the manner in which the tax revenues are recycled (returned) to the economy. The results also reveal significant heterogeneity in welfare impacts within household income groups, thus highlighting the importance of accounting for household heterogeneity in tastes and car-ownership in evaluating distributional impacts.

II. Structure of the Simulation Model

A. Household Demands

Households obtain utility from car ownership and use, as well as from consumption of other commodities. Utility from driving depends on characteristics of the automobile and vehicle-

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[3] The one exception is a recent working paper by Feng, Fullerton, and Gan (2004).
[4] Prior studies have tended to focus on policies' impacts on prices or quantities, rather than the welfare consequences.

miles traveled. 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). Households without car endowments simply choose whether to purchase a car.

U.S. auto markets include thousands of types of new and used cars and trucks, and many households own several vehicles. Households enjoy 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 group cars and trucks into 284 categories based on the vehicle'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 depends on the number of adults in the household. On each occasion, the household makes a discrete choice of whether to choose one of the 284 composite cars. If the jth automobile is chosen, the household then makes a continuous choice of VMT for the automobile. A virtue 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 specifically, we assume that household preferences on the tth choice occasion ($t=1,…,T$) for the jth automobile ($j=1,…,J$) can be represented by the conditional indirect utility

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[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 in which households choose alternative bundles of cars. Feng, Fullerton, and Gan (2004) have tried this approach, which has the attraction of permitting greater interdependencies among a household's automobile choices. A drawback is that, in order to keep tractable the dimensionality of the consumer's choice set, it requires a great deal more automobile aggregation as well as restrictions on the number of cars households can own.

function $U_{tj} = V_j(y/T - r_j, u_j, \boldsymbol{q}_j, \boldsymbol{z}, \boldsymbol{\beta}) + \varepsilon_{tj}$, where y is household income, r_j, u_j, and $\boldsymbol{q}_j$ are

automobile j's one-year rental price, per-mile utilization price (i.e., operating cost), and non-price

characteristics, respectively. The vector $\boldsymbol{z}$ contains household's characteristics, $\boldsymbol{\beta}$ is a parameter

vector that varies randomly across households, and ε_{tj} 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 car 0), her preferences can be

represented by $U_{t0} = V_0(y/T, \boldsymbol{z}, \boldsymbol{\beta}) + \varepsilon_{t0}$. The rational household chooses the alternative that

maximizes its utility. Assuming that each ε_{tj} 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 β takes the standard conditional logit form. Because we employ a

theoretically consistent preference specification, we can use Roy's identity to derive the

conditional VMT demand for the chosen automobile.

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 acts in accordance with Bertrand competition, setting the

prices for its fleet of automobiles to maximize profits, given the prices set by its competitors. New

cars differ by class and manufacturer. Let k index a given producer. Let Φ represent the set of

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[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.

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

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

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

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. $\boldsymbol{p}$ denotes the vector of *all* new car prices. The two constraints 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, all car prices (and associated markups) must be solved for simultaneously.

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. 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.

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

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[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.

profit-maximization (first-order) conditions and that clears the used-car market. 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.

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 economic, demographic, and geographic data. From

several other sources (see appendix) we obtained information on car characteristics (e.g., weight,

horsepower, wheelbase, and fuel-economy) and operating costs.

In designing an estimation approach, two issues were especially important. First, for

consistent welfare assessments we wanted to estimate simultaneously and consistently the

household's choice of VMT and car type. The two-step estimation strategies in previous studies

(e.g., Goldberg (1998), West (2004)) did fully integrate these decisions. 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 developed a random-coefficient repeated discrete-

continuous model permitting simultaneous estimation of households' car and VMT choices.

Random-coefficient specifications can generate more plausible structures of substitution relative to

fixed parameter models (Train, 2003), and recently developed simulation-based techniques now

make the estimation of these models computationally feasible. We estimate our random-

coefficient model within a Bayesian framework, using a variation of Allenby and Lenk's (1994) Gibbs Sampling algorithm.

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 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 change. The corresponding average excess burdens (efficiency cost divided by taxes collected) are

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

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. 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. The main 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.

B. Distributional Impacts

Table 2 displays the distributional impacts of a 30-cent gas tax increase for households

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.[10] 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%. The cost of the policy

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[10] 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.

relative to income is highest for households not retired and with children. 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. 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 owners[11] 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.   **Future Work**

This is our first application of the model. Several improvements and new applications are planned. The present model only considers a policy's impacts in the year of its implementation. We currently are expanding the model to enable it to examine long-run effects associated with the gradual evolution of the automobile fleet. We also are exploring alternative ways to deal with the potentially very high dimensionality that arises from the multitude of car types and car

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[11] Every household has some positive probability of purchasing or retaining a car. High-probability car owners here are those for which the probability of purchasing or retaining a car exceeds 25 percent per choice occasion.

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 Increases[1]

	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%

[1] Dollar figures are in 2001 dollars; "Avg" indicates a weighted average figure per household

[2] High MPG cars include those classes with an average fuel economy over 23.6 mpg (five of our ten classes)

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

Tax-Based Recycling

Income (000's)	All Households	Retired	Not Retired, No Children	Not Retired, Children	High Prob. Car Owner	Low Prob. Car Owner
EV (% of Base Income)						
<25	-0.103%	-0.093%	-0.104%	-0.119%	-0.110%	-0.084%
25-50	-0.108%	-0.105%	-0.105%	-0.113%	-0.110%	-0.089%
50-75	-0.098%	-0.089%	-0.103%	-0.099%	-0.098%	-0.099%
>75	-0.092%	-0.094%	-0.092%	-0.091%	-0.092%	-0.091%
% Change in VMT						
<25	-5.43%	-4.87%	-5.45%	-6.39%	-5.48%	-5.31%
25-50	-5.69%	-5.70%	-5.60%	-5.78%	-5.61%	-6.29%
50-75	-5.59%	-5.42%	-5.69%	-5.58%	-5.53%	-6.59%
>75	-5.35%	-5.70%	-5.11%	-5.49%	-5.24%	-7.38%

Income-Based Recycling

Income (000's)	All Households	Retired	Not Retired, No Children	Not Retired, Children	High Prob. Car Owner	Low Prob. Car Owner
EV (% of Base Income)						
<25	-0.216%	0.033%	-0.311%	-0.482%	-0.429%	0.356%
25-50	-0.205%	0.038%	-0.164%	-0.403%	-0.281%	0.393%
50-75	-0.077%	0.132%	-0.116%	-0.113%	-0.102%	0.360%
>75	0.079%	0.189%	0.093%	0.046%	0.063%	0.368%
% Change in VMT						
<25	-5.42%	-4.74%	-5.49%	-6.50%	-5.56%	-5.05%
25-50	-5.75%	-5.59%	-5.63%	-5.99%	-5.73%	-5.91%
50-75	-5.67%	-5.33%	-5.77%	-5.70%	-5.63%	-6.20%
>75	-5.23%	-5.36%	-5.00%	-5.40%	-5.14%	-6.81%