CONSUMER VALUATION OF FUEL ECONOMY: A MICRODATA APPROACH

James M. Sallee, University of Chicago
Sarah E. West, Macalester College
Wei Fan, RVI Group

INTRODUCTION

SINCE THE AMOUNT OF CARBON RELEASED BY A gallon of gasoline is independent of the manner in which it is combusted, if consumers acknowledge the full value of fuel economy, a tax on gasoline could reduce greenhouse gas emissions as efficiently as a tax on emissions.[1] If, however, consumers do not sufficiently value fuel economy when making the decision about what car to buy, an additional complementary policy, such as a fuel economy standard or a feebate, can be welfare improving (Fischer, Harrington, and Parry, 2007; Greene, Patterson, Singh, and Li, 2005; and Train, Davis, and Levine, 1997). We use microdata on used vehicle prices and a unique identification strategy based on micro-level variation in vehicle odometers to test whether used car prices change by the amount predicted by a fully rational asset pricing model.[2]

Intuitively, our approach is to first compare the prices of two used cars that are identical except in their current odometer readings – and therefore in the remaining future operating costs – and second to repeat this comparison when different gasoline prices prevail. This is conceptually similar to a difference-in-difference approach. Importantly, the fact that the difference is *within* vehicle type allows us to provide an exceptionally rich set of controls, including time-period shocks and depreciation schedules that are unique for each vehicle type. To execute this research design, we employ used vehicle price data that include actual transaction prices, dates of sale, vehicle identification numbers (VINs), and odometer readings. If consumers fully value fuel economy, then there will be a one-to-one relationship between the present value of expected fuel costs and the price of a vehicle.

A few papers attempt to directly test whether or not car prices fully adjust.[3] Kahn (1986) develops a panel estimation procedure to test a model of asset valuation in the used car market, and this panel approach is extended by Kilian and Sims (2006).[4] Allcott and Wozny (2009) takes a different approach to arrive at the same location, identifying the effect of gasoline prices on the demand for fuel economy using a discrete choice framework that exploits consumer substitution between new and used vehicles and of varying fuel efficiencies. Our approach differs critically from this existing literature in the assumptions necessary to motivate estimation. Kahn (1986) and Kilian and Sims (2006) implicitly assume that unobservable vehicle characteristics are constant within model across model year. Allcott and Wozny (2009) relax that assumption but assume that changes in vehicle characteristics across model years are uncorrelated with gasoline price changes. This may be incorrect if automakers make vehicle modifications between model years, which is suggested in both Linn and Klier (2007) and Sallee and Slemrod (2009).

Our preliminary baseline results indicate that used car prices adjust by about 80 percent of the amount predicted by theory, and sensitivity analysis suggests that for a reasonable discount rate, they adjust by the full amount. Our findings therefore suggest a limited role for complementary policy tools. These results contrast with those from previous papers, which find adjustment closer to 25 percent. We interpret the results of this exercise as a test of whether or not consumers fully recognize the value of fuel economy, though we acknowledge that with our current specification, we can only jointly test assumptions about the discount rate, gasoline price expectations, and rationality.

The next section outlines our estimation strategy. The third section describes the data, the fourth section explains our estimation strategy, the fifth section presents preliminary results, and the sixth section concludes.

ESTIMATION STRATEGY

Our estimation strategy is based on exploiting variation in the expected future fuel cost of vehicles resulting from differences in the odometer reading and the price of fuel at the time a vehicle is sold. For example, suppose that two 2005 Toyota Camrys are sold in November 2009, one with 80,000 miles on the odometer and the other with 90,000 miles. The price difference between these two cars should reflect the difference in value of having a lower mileage vehicle (which is in better condition and has a longer expected remaining life) net of the larger operating costs, which are a function of fuel prices. Next, imagine that the price of gasoline changes between November 2009 and December 2009, and that in December two other 2005 Toyota Camrys, one with 80,000 miles and the other with 90,000 miles, are sold. Now, the price difference should reflect the same factors as before, and the difference-in-difference should reflect only the change in operating costs that resulted from the gasoline price change. There may be many factors that affect the *level* of these prices, but as long as these factors have the same effect on an 80,000-mile Camry and a 90,000-mile Camry, they can be differenced out.

Because we use a continuous measure of odometer readings, our final estimating equation is not literally a difference-in-difference. We regress used-vehicle transaction prices on an odometer polynomial, time period fixed effects, and a measure of the discounted expected future operating costs of vehicles. Importantly, we allow the odometer polynomial and the time period fixed effects to vary for each vehicle type – where a type is defined by all observed characteristics, including model, model year, cylinders, displacement, transmission, and trim. We are able to do this and still identify the parameter because we use individual transaction prices and use variation in fuel costs *within* a car type and time period by exploiting the odometer information. This contrasts sharply with other recent work, which must restrict these coefficients to be the same across some set of vehicles and time periods in order to identify the parameter.

To arrive at our estimation equation, we start with a simple model of the price of used cars which assumes that the used car market is competitive and the supply of used cars is inelastic. Under these assumptions, the expected discounted price, P, of an individual observed vehicle i of type j at time t is equal to the expected discounted driving value $V(\cdot)$ over its remaining lifetime, minus the expected discounted values of fuel costs $C(\cdot)$, and maintenance costs $Z(\cdot)$:

$$\textbf{(1)}\quad P_{ijt} = V(O_{ijt},X_j,r) - C(O_{ijt},m_{ijt},g_t,MPG_j,r) - Z(O_{ijt},X_j,r)$$

where O is odometer reading, X is a vector of vehicle attributes, m is per period miles driven, g is the price of gasoline, MPG is the vehicle's fuel economy in miles per gallon, and r is the discount rate.

The expected discounted value of fuel costs, $C(\cdot)$, is given by:

$$\textbf{(2)}\quad C_{ijt} = E_t\left[\sum_{s=t}^{R} H(O_{ijt},X_j)\frac{1}{(1+r)^{s-t}}\frac{m_{js}g_s}{MPG_j}\right],$$

where R is the final period in which vehicles are scrapped, and $H(\cdot)$ is the probability of survival of a vehicle as a function of its odometer reading and its attributes.

Since the functions $V(\cdot)$ and $Z(\cdot)$ do not depend on the price of gasoline ($\partial P_{ijt}/\partial g_t = -(\partial C_{ijt}/\partial g_t)$), we could use a panel estimation strategy, where the variation in gasoline price interacts with fuel economy to enable identification at the vehicle level. But this requires that all vehicles experience the same time period shock and the same depreciation schedule. Rather than impose these rather stringent assumptions, instead we identify the effects of gasoline price changes on vehicle price using variation in odometer readings at the vehicle level, using the following estimation equation:

$$\textbf{(3)}\quad P_{ijt} = \beta C_{ijt} + \sum_{a=1}^{4}\alpha_a O_{ijt}^{a} + \delta_{jt} + \varepsilon_{ijt}$$

where the odometer terms O and their coefficients are specific to each vehicle type j, and the δ_{jt} are time-vehicle type fixed effects, where time is measured in months. The odometer polynomial is an approximation to the V and Z functions. Our null hypothesis is that β equals negative one, that there is a one-for-one relationship between the present discounted value of real remaining fuel costs and real vehicle price. This implies full adjustment.

Estimation of equation (3) requires vehicle-specific odometer terms, which enter estimation as odometer terms interacted with vehicle indicators. As our unit of vehicle observation is at the level of truncated VIN, running the estimation on even a subsample of our data hits computational memory constraints, as the number of independent variables is enormous. We therefore invoke the Frisch-Waugh-Lovell theorem (Frisch and Waugh, 1933; Lovell, 1963), which allows us to break down the estimation procedure into steps that are less memory-intensive (albeit still very computation-time-intensive). This yields a coefficient on the residuals from the cost equation that is numerically identical to the β in equation (3).

DATA SOURCES AND VARIABLE DERIVATION

Our used-car price data come from a large sample of wholesale used-car price auctions. The data include the transaction price, transaction date, odometer reading, and truncated VIN of each vehicle sold in several large auction houses. This market does not include individual end users. In addition to automotive dealers, businesses and governments that own large fleets sell vehicles on these auctions. The buyers are primarily used-car dealers, who subsequently resell the vehicles to consumers. Many of the transactions in these markets are between dealers, who use these auctions as a way to reshuffle their inventories.

Our data sample includes over 90 million transactions that took place between 1990 and 2009. We match these vehicles to official EPA fuel economy ratings using all available information on model, model year, cylinders, displacement, body type, transmission, and trim. In the estimation, we use the combined EPA fuel economy rating. After dropping vehicles whose fuel economy we cannot obtain, and taking a 10 percent sample (for computational reasons), we are left with around 8 million transactions in the estimation sample.

For the price of gasoline, we use the tax inclusive, monthly national retail price of gasoline from the Energy Information Administration (EIA). We adjust these and the vehicle prices using the CPI-U price series. The estimates presented here assume that consumers' expectations of gasoline prices follow a random walk, though we are experimenting with alternative specifications.

Construction of our future fuel cost function is critical to our estimation. We estimate mileage and scrappage probabilities by using Lu (2006), transforming her results so that they are in terms of odometer, which we consider a better measure of age than years. We use our auction data to adjust expected future miles by make and class according to how much each make-class category is driven compared to the average across all makes. We assume that no vehicle lasts more than 25 years from the time it is observed, use a discount rate of 5 percent for our baseline estimates, and conduct sensitivity analysis using rates of 10 percent and 15 percent. A complete explanation of our variable construction and planned improvements can be found in Sallee, West, and Fan (2010).

Table 1 presents summary statistics for our estimation sample.

PRELIMINARY RESULTS

Table 2 reports preliminary results for the full sample and a selection of subsamples. For the full sample, the coefficient on cost is -0.788, implying that for every one dollar increase in fuel costs, used

Table 1
Summary Statistics

Variable	*Mean*	*Std. Dev.*
Nominal Vehicle Sale Price	9260.32	6529.70
Real Vehicle Sale Price ($1982-84)	5209.61	3657.68
Present Value Real Remaining Fuel Cost ($1982-84)	3076.19	1573.26
Nominal Gas Price ($)	1.78	0.75
Real Gas Price ($ 1982-84)	0.96	0.29
Odometer (miles)	57274	43726
Age (years)	3.88	3.31
Fuel Economy (EPA Combined MPG)	22.23	4.62
% Car	0.64	.
% Light-duty truck	0.36	.
Number of observations	8106030	

Table 2
Preliminary Baseline Estimation Results Coefficients on the Present Value of Real Remaining Fuel Costs

	Full Sample	
	-0.788	
	(0.011)	
	Subsamples	
	Passenger Cars	*Light Trucks*
All	-0.851 (0.018)	-0.736 (0.014)
Chevrolet	-0.599 (0.045)	-0.727 (0.033)
Ford	-0.513 (0.030)	-0.735 (0.033)
Honda	-0.787 (0.034)	-0.619 (0.048)
Toyota	-0.914 (0.054)	-0.792 (0.043)

Standard errors are reported in parentheses.

Table 3
Sensitivity of Results with Respect to the Discount Rate (All Vehicles)

Discount Rate	*5%*	*10%*	*15%*
Cost Coefficient	-0.788	-1.01	-1.24
Standard Error	(0.011)	(.014)	(.018)

vehicle price falls by about 79 cents. While this estimate suggests that consumers' valuation of fuel economy is incomplete, it is substantially closer to negative one than the results of other recent studies.

Estimation on a set of subsamples reveals some intriguing heterogeneity in price adjustment across vehicle classes and makes, with vehicle price adjustment rates ranging from just over 50 percent for Ford cars to over 90 percent for Toyota cars. Overall, car prices adjust more fully than do light-duty truck prices, though the pattern is inconsistent within makes.[5]

We also run the estimation on the full sample of vehicles imposing discount rates of 10 percent and 15 percent. Table 3 shows that if the discount rate is 10 percent, our coefficient of interest equals -1.01; consumers fully adjust to changes in the present discounted value of remaining operating costs. Estimation imposing a discount rate of 15 percent implies overadjustment, underscoring the importance of careful construction of the cost term, and the determination of what constitutes a "reasonable" discount rate.

Our results contrast with some recent work that attempts to estimate the same parameter in the car market. Most notably, Allcott and Wozny (2009) and Kilian and Sims (2006) both find significant underadjustment, with principle estimates hovering around 25 cents on the dollar. Both of these papers use a panel identification strategy that requires unobservable vehicle attributes to be common across model years. Both papers also make restrictions across vehicles regarding the depreciation schedules for vehicles and the time period effects. Importantly, when we restrict our estimator to impose the same odometer polynomial coefficients and the same time period fixed effects within a make, our estimates fall dramatically and become closer to zero than negative one. This suggests that even within a carmaker, the depreciation schedules and time period effects are different enough that imposing such restrictions causes a qualitative change in the analysis. Without a theoretical justification for imposing these restrictions, we think it is preferable to relax these assumptions, which we are able to do given our use of odometer variation.[6]

CONCLUSION

We use vehicle transaction data combined with EPA fuel economy ratings and gasoline prices to estimate the extent to which used vehicle prices adjust to changes in the present discounted value of operating costs. We identify the effect of gasoline prices not with time- and fuel-economy-based variation in operating costs across different vehicles, but instead with *odometer*-based variation in expected operating costs within tightly defined vehicle types. That is, we compare the effect of a gasoline price shock on the price of a vehicle with many miles remaining to the price of an identical vehicle with few miles remaining.

We interpret the results of this exercise as a test of whether or not consumers fully recognize the value of fuel economy. With our current specification, we can only jointly test assumptions about the discount rate, gasoline price expectations, and rationality. That is, incomplete consumer valuation of fuel economy could just as easily be due to consumers employing a discount rate that is too high as it is due to consumers underestimating the lifetime of a vehicle, having faulty gasoline price expectations, or being boundedly rational. Disentangling the effects of these potential sources of undervaluation remains a fruitful area for future research.

Preliminary baseline results, which assume a discount rate of 5 percent, indicate that for a dollar increase in operating costs, used vehicle prices fall by 79 cents. While this estimate is consistent with the general finding of underadjustment, it is closer to full adjustment than found by papers in the recent literature. And, our estimate assuming a 10 percent discount rate implies that adjustment is full. While our work is still progressing, these results, which contrast with some other recent findings, are important because they suggest that policies other than a gasoline tax are unlikely to be justified on the grounds of incomplete consumer valuation of fuel economy.

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Notes

[1] See Parry, Walls, and Harrington (2007) for a thorough review of the relative efficiency of policies for the reduction of vehicle pollution.

[2] This paper presents preliminary estimates from an ongoing research program. Our complete working paper is Sallee, West, and Fan (2010).

[3] The literature on energy intensive durables has found very large implied discount rates, which may be a symptom of underadjustment or myopia (Hausman, 1979, Dubin and McFadden, 1984). On the other hand, Dreyfus and Viscusi's (1995) results imply discount rates that are roughly the same as those on used-vehicle loans, suggesting that consumers in vehicle markets are not shortsighted.

[4] A recent body of literature also uses panel methods for identification, but does not estimate undervaluation parameters. Linn and Klier (2007) examines the effect of changes in national-level gas prices on the demand for fuel efficiency, but consider effects on quantities (as opposed to prices) of new cars. They find that a $1 increase in the price of gasoline results in a 0.5 miles per gallon increase in fuel economy, on average. This estimate fits neatly into the range of estimates in Li, Timmins, and von Haefen (2009), which examines the effects of changes in gasoline price on registrations of both used and new vehicles. Busse, Knittel, and Zettelmeyer (2009) examine the response of new car transactions to gasoline prices on several margins, including how average prices change for vehicles in different quartiles of the fuel economy distribution.

[5] Sawhill (2008) finds substantial heterogeneity across consumers (where the unit of observation is actually a model year market share) but does not explore the dimensions along which this heterogeneity occurs.

[6] Our results are consistent with the findings of Busse et al. (2009), who do not attempt to directly estimate the degree of adjustment, but provide a back-of-the-envelope calculation comparing their estimates to a fully rational benchmark and conclude that price adjustments in the used-car market are consistent with full adjustment.

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