Automobile Fuel Economy: Under-valued, Over-valued, or Both?

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Introduction

Even before the oil crisis of the early 1970s, concern over energy efficiency had been an ongoing public concern, waxing and waning over the decades. The September 11 terrorist attacks in 2001 and the subsequent spike in oil price, followed by Hurricane Katrina in 2005, then economic crisis of 2008 and $5 a gallon gasoline in some parts of the country, intensified interest in automobile fuel economy and tied general concerns over air pollution, global warming, and energy conservation more strongly with energy security. In December 2007, President Bush signed the Energy Independence and Security Act into law, mandating a 27% increase in fuel economy standards, from 27.5 miles per gallon to 35 miles per gallon, to be achieved by 2020. This law also extended to light trucks (including most sport utility vehicles), eliminating the lower standard for these vehicles. The Obama administration first pushed up the date for achieving this standard, then raised the bar to 54.5 mpg for cars and light-duty trucks by model year 2025.

While fuel economy decreased 12 percent between 1987 and 2004, both vehicle weight and zero to 60 acceleration increased approximately 30 percent. This shows that consumers bought more vehicle and more horsepower per pound of vehicle with only a small sacrifice in terms of operating costs. In addition, continuing improvements in technology are producing lighter vehicles and improving fuel economy, while higher fuel prices hurt sales of larger vehicles. To understand the impact of legislatively mandated increases in fuel economy, it is critical to know how consumers value fuel economy and other vehicle characteristics. To the extent that fuel economy is valued for fuel savings provided, and to the extent that fuel prices reflect the true value of that fuel, markets should produce an efficient mix of vehicles in terms of fuel economy. This research focuses on the first part of this equation, how consumers value fuel economy, in particular, across the continuum of fuel economy, and whether or not this value accurately reflects the value of fuel savings.

While previous research has estimated the value of automobile fuel economy using hedonic analysis, this research adds to this literature by examining whether or not there are systematic miscalculations of the value related to the level of fuel economy based on new car purchase prices. This research will take advantage of a newly developed data set covering 2001 to 2010 to estimate any potential bias for each year and compare it over time, thus also examining the relationship between fuel prices and the degree of over- or under-valuation.

Previous Literature

Numerous previous studies have found that new car and fleet average fuel economy have increased in times of higher gasoline prices, indicating that consumers shift their purchases towards more fuel efficient vehicles as gas prices rise, demonstrating that consumers do consider fuel economy in their automobile purchase decisions (Li et al 2009, Busse et al 2009, Klier and Linn 2010).

Among earlier hedonic studies of automobile fuel economy, Thompson (1987) and Arguea and Hsiao (1993) assumed a linear, rather than inverse, relationship between miles per gallon and automobile prices and, not surprisingly, found an inconsistent and insignificant correlation. Other analysts properly accounted for the inverse relationship between automobile price and miles per gallon, but created a fuel cost variable by assuming a fuel price (Atkinson and Halvorsen 1990, Dreyfus and Viscusi 1995, and Berry, Levinsohn, and Parks 1995).

Espey and Nair (2005) also appropriately considered the inverse of miles per gallon in their analysis, as well as the uncertainty consumers face regarding future fuel prices, but they did not consider the potential uncertainty associated with consumers' expectations of fuel economy, nor did they include sport utility vehicles. Furthermore, their analysis, along with most of the others, reviews only one year of fuel prices during a period when fuel prices had been relatively stable for nearly a decade.

More recent work has focused on environmental factors influencing consumers' vehicle choice. Kahn (2007) analyzed the geographical distribution of Green Party members in California in relation to various measures of household transportation patterns and vehicle choice, concluding that vehicle choice is influenced by "environmentalism" for at least some people. Potoglou and Karoglou (2007) use stated choice to examine factors influencing household choice preferences for cleaner vehicles in Hamilton, Canada, finding positive stated willingness to pay for low emission vehicles. In comparison, any hedonic analysis is limited in that the portion of any value associated with fuel economy that is related to expected fuel savings versus that related to environmental consciousness cannot be determined. However, an estimated value of fuel economy greater than the associated fuel savings would suggest a willingness to pay for something correlated with fuel economy, for example, lower emissions or decreased reliance on foreign oil.

Turrentine and Kurani (2007) conclude that consumers value fuel economy for more than just the private savings, based on household level interviews. In contrast, Alcott (2011) analyzed the Vehicle Ownership and Alternatives Survey and determined that consumers underestimate fuel cost savings at low levels of MPG and overestimate the savings at high levels of MPG. Estimation of consumer valuation could play a critical role in recent lawsuits such as those against Hyundai and Ford ("Espinosa, et al. v. Hyundai Motor American, et al." and "Pitkin v. Ford Motor Company"), both accusing the automobile producers of advertising inaccurately high fuel economy for certain models of cars, thus being able to extract higher payments from new car buyers than if accurate measures of achievable level of fuel economy were known to buyers.

This study builds on previous hedonic analyses of vehicle choice, examining the market for both cars and sport utility vehicles and exploring how different expectations of fuel economy might influence consumers' valuation of improvements in fuel economy and what the estimated values might suggest about consumer expectations of future fuel prices. Between 2001 and 2006, gasoline prices increased by more than 70 percent. As fuel prices increased and become more unstable, one would expect that consumers re-evaluated the importance of fuel economy in their automobile choices. This research first examines the sensitivity of estimates of the value of fuel economy to the measure of fuel economy used in the estimation as whether or not valuation changes in relation to the level of fuel economy. This value will be estimated for each of ten year to also determine variation over time.

Methodology

The demand for automobiles is derived from the demand for transportation services. The utility consumers derive from automobile travel depends, at least in part, on vehicle comfort, safety, driving performance, and the cost of travel. The cost of travel is a function of fuel prices, miles driven, and fuel economy. For a given price of fuel and miles driven, higher fuel economy reduces travel costs. Thus, holding all other vehicle characteristics constant, consumers could pay as much more for a more fuel efficient vehicle as the amount of fuel savings generated, and be just as well off as paying less for a vehicle with lower fuel economy. Some people, however, may also value improvements in fuel economy for environmental or energy security reasons. Further, higher fuel economy often comes at the expense of vehicle size, power, and/or safety, making valuation of fuel economy more complex than a simple fuel savings calculation. Automobile markets in the United States reflect the wide range of consumer tastes and preferences in our society, resulting in a rich variety of "bundles" of vehicle characteristics available.

Hedonic regression analysis can be used to take advantage of this range of automobile choices to estimate the contribution of each quantifiable characteristic to the vehicle price. The demand for automobiles is derived from the demand for transportation services. The utility a consumer derives from automobile travel depends, at least in part, on vehicle characteristics such as comfort, safety, and performance. Fuel economy would be valued primarily in relation to the impact it has on travel costs. All of these values would be reflected in the price of automobiles, each of which is a differentiated bundle of characteristics, such that $P_{auto}=f(A_1, A_2, \ldots, A_n)$, where each A_i is a characteristic or attribute of the vehicle. The implicit marginal value of any one attribute then is the partial derivative of the equilibrium hedonic price function with respect to that attribute.

It is most important to note that fuel economy enters the model inversely, such that the value derived from improved fuel economy truly reflects fuel savings according to: Savings=(price per gallon)*(miles travelled)/(miles per gallon), discounted. Thus the incremental value of an improvement in miles per gallon declines as miles per gallon rises, as an additional mile per gallon offers less in savings at higher levels of fuel economy. On the other hand, the marginal (negative) value of an additional gallon per mile should be constant, regardless of the level of fuel economy, as the price of gas does not depend on the fuel economy of the vehicle being filled up. Thus the coefficient on gallons per mile is expected to be negative, reflecting that vehicle price will decrease as the vehicle requires more gallons per mile driven.

Conversely, vehicle price will be higher when fuel economy improves, meaning fewer gallons are required per mile driven.

Perhaps the simplest way to estimate if the (negative) value of gallons per mile varies with the level of fuel economy is to introduce a squared term. A positive coefficient on the square of gallons per mile would imply an improvement in fuel efficiency (fewer gallons per mile) would be valued more at higher levels of fuel economy (miles per gallon) and valued less at lower levels of mpg, even though it would save the same in travel costs, all else constant. This could be rational if consumers buying more fuel efficient vehicles expect to drive those vehicles more, or if they value the associated environmental or energy security benefits of reduced fuel use more than those buying lower mpg vehicles.

A slightly more complex way to estimate variation in value of gallons per mile across vehicles of different levels of fuel economy is to use linear spline regression. Suppose there is simply a break in the estimated value at a specific point in the range of fuel economy, t. Then instead of the regular linear regression $Y=\alpha + \beta_0 X + \varepsilon$, introduce a dummy variable $D=0$ for $X<t$ and $D=1$ for $X \geq t$ where X is gallons per mile and t is the relevant point of change in valuation measured in gallons per mile. The new model is then $Y=\alpha + \beta_0 X + D\,\beta_1(X-t) + \varepsilon$. For X below t, the model is the standard linear regression. For $X \geq t$, the slope becomes $\beta_0 + \beta_1$. For multiple breaking points $t_1, \ldots t_k$, multiple dummy variables can be created such that $D_i = 0$ for $x < t_i$ and $D=1$ for $x \geq t_i$ then the model becomes $Y=\alpha + \beta_0 X + \sum_{i=1}^{k} D\,\beta_i(X-t_i) + \varepsilon$, with k+2 parameters to be estimated.

Data

Wards Automotive Group, Consumer Reports, Edmunds.com, and the National Highway Traffic Safety Administration (NHTSA). Wards Automotive Group collects data about all new vehicles sold in the United States by make and model. This data includes a variety of measurements of vehicle size, weight, engine type, horsepower, EPA fuel economy, manufacturer's suggested retail price, and sales. U.S. EPA reports city and highway mileage, as well as a weighted average based on an assumption of 45% highway driving and 55% city driving. Consumer Reports conducts its own tests of vehicle performance and reports city, highway, and an average value for some years, but only an average value for other years. The average is based on a 50/50 weighting of the highway and city mileage as well as on a separate mixed-use extended drive. Consumer Reports' fuel economy values average about 93% of the EPA values, but range by close to 25% in either direction of the EPA values. Consumer reports also includes a measure of acceleration, braking, vehicle classification (e.g. luxury or SUV), reliability, comfort, and safety for most of the vehicles it tests. Consumer Reports safety information is a summary of the NHTSA crash tests. Summary statistics for the variables used in this analysis for 2005 are shown in Table 1.

Curb weight will be used as a proxy for size and acceleration will be used for power. While horsepower is a common measure of vehicle power, acceleration is a better reflection of relative power and is less highly correlated with curb weight than is horsepower, improving the accuracy of the estimation. Turning circle (the bumper clearance needed to make a U-turn) will be used as a measure of performance. Braking distance, the distance necessary to come to a stop on dry pavement from a speed of 60 miles per hour, and crash test results will be used to reflect vehicle safety. Consumer Reports comfort and reliability ratings will be included as well. Variables will also be included to reflect luxury vehicles and sport utility vehicles and vans.

Other vehicle type indicator variables are not necessary as the other included vehicle characteristics, in particular size, power, and performance, capture the differences across these vehicles. 87% of new car sales and about 75% of SUV and van sales are represented in the data set. About 65% of total sales of what are classified as light trucks are SUVs and vans.

Figure 1 shows the relationship between vehicle price and 0-60 acceleration time, indicating that, in general, vehicle price increases as acceleration improves. Figure 2 shows the relationship between vehicle price and curb weight, showing that heavier vehicles are generally more expensive than lighter vehicles, with most light trucks being heavier than most cars, and rising along a different trajectory in relation to vehicle weight than cars. Figure 3 illustrates the general inverse relationship between vehicle price and fuel economy that holds for both cars and light trucks.

Empirical Results

The data set was first divided into cars and light trucks. Four models were run for each of these subcategories of vehicle sales. The first model for each used EPA weighted average fuel economy figures, the second used Consumer Reports reported average fuel economy, the third model used Consumer Reports fuel economy and included a dummy variable for above average fuel economy to estimate if there is a difference in valuation above and below average fuel economy. Finally, each data set was subdivided further in terms of fuel economy to estimate finer gradations in valuation differences. Cars were subdivided approximately into quartiles, light trucks (vans and SUVs) were subdivided approximately into thirds since there were fewer available models of vans and SUVs. Finally, the complete data set including cars, SUVs, and vans was merged and estimated using EPA fuel economy values, Consumer Report fuel economy values, a squared term for fuel economy, and quintiles of fuel economy. This data set was first estimated with dummy variables for each explanatory variable for the SUV/vans, but only the comfort and luxury variables were statistically significantly different from the cars, so the rest of the models only included these separately for cars and SUV/vans. A dummy variable was also included for vans and for SUVs.

For the 2005 data, fuel economy is not statistically significant in most of the models. Curb weight, acceleration, comfort rating, and luxury classification are significant in all of the models. The adjusted R-squared is about 0.83 for each of the car only models, 0.73 for the light trucks, and 0.83 for the merged data set. The results of these estimations suggest that consumers do not value fuel economy at all in new vehicle purchase decisions, at least in 2005. More vehicle characteristic data is available, so subsequent modeling efforts will explore other variables that may influence purchase decisions, as well as examining different ways of subdividing the data set to match choice sets consumers may face in the market, and finally, adding several more years of data, 2002-2010, to determine if 2005 was perhaps an anomaly, or if this results holds up consistently over the decade.

Conclusions

If automobile buyers overestimate the value of fuel economy at higher levels of MPG, the inefficiency of misconceptions of fuel savings cannot be remedied by higher fuel economy standards, but possibly by more accurate information about potential fuel savings. On the other hand, if consumers underestimate the value of fuel cost savings at the low end of MPG, calls for higher standards that would raise the bottom end up might be merited based on efficiency.

It is also possible that undervaluation at lower levels of fuel economy is a reflection of alternative means of paying for fuel economy, that is, sacrifices in power and/or size would be much greater or even infinite, in the sense that there may be no vehicles that can provide the power, size, and comfort of a full size car and also attain 40 mpg. For example, there was only one 2005 vehicle in the upper half of the range of vehicle weight that was above the average level of fuel economy (about 22 miles per gallon). However, in the lower half of the range of curb weight, fuel economy varied from 18 miles per gallon to 51 miles per gallon. Future modeling efforts will consider more years and alternative mark segments such as large versus small vehicles rather than just cars versus light trucks to reflect that choices by some may be constrained first by vehicle size, with fuel economy a secondary consideration within the class of vehicles that satisfy the size choice.

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Table 1: Summary Statistics for 2005 Model Year Vehicles

	Cars			SUVs and Vans		
Variable	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Price	24,404	11,044	76,020	30,891	20,515	55,590
Curb Weight	3149	1589	4464	4257	3090	5528
0 to 60 Acceleration (seconds)	8.7	5.1	12.0	9.3	6.4	11.9
Turning Circle (feet)	39.2	34	45	40.7	37	46
60 to 0 Braking Distance (feet)	138.5	116	154	141.7	127	155
Comfort Rating (1-5)	4.0	3	5	3.8	2	5
EPA average MPG	26.2	17.8	64.0	19.0	14.5	25.7
Consumer Reports average MPG	22.9	16.0	51.0	16.6	12	21
SUV				74.7%		
Van				25.3%		
Luxury	5.6%			1.2%		
Number of models	94			60		
Total sales	6,671,487			3,208,628		
Percent of total sales in data set	87%			74.4%		

Table 2: Empirical Results for 2005 Model Year Cars

	Model 1	Model 2	Model 3	Model 4
Intercept	15,445	14,645	19977	7897
Curb Weight	7.87***	7.60***	7.72***	7.62***
Acceleration	-1864.8***	-1820.1***	-1896.7***	-1833.8***
Turning Circle	83.1	73.9	123.3	99.9
Braking Distance	-143.4	-142.9	-143.1	-143.9
Comfort Rating	4314.1***	4335.1***	4451.2***	4347.8***
Luxury	20,443***	20,444***	19,737***	19,601***
EPA gallons per mile	-7492.2			
Consumer Reports gallons per mile		25836	-162578	150030
Gallons per mile for below average MPG			368007	
GPM for 20 to 22 MPG				-96807
GPM for 23 to 25 MPG				-120079
GPM for MPG over 25				421599
Adjusted R-squared	0.831	0.831	0.834	0.833

***, **, * significant at 1%, 5%, and 10% levels respectively

Table 3: Empirical Results for 2005 Model Year Light Trucks (SUVs and Vans)

	Model 1	Model 2	Model 3	Model 4
Intercept	-28,735*	-32,699**	-37,839*	-35,320*
Curb Weight	6.68***	9.41***	9.28***	9.44***
Acceleration	-1426.7**	-1431.9**	-1475.3***	-1430.6**
Turning Circle	591.0*	528.9*	531.6*	537.5*
Braking Distance	39.8	121.1	136.4	121.5
Comfort Rating	2505.5***	2126.8**	2210.7**	2148.7**
Vans	-3628.4**	-5167***	-5219.5***	-5190.9***
Luxury	5788.3	5280	5230.7	4993.5
EPA gallons per mile	110518			
Consumer Reports gallons per mile		-143006	-78933	-104631
Gallons per mile for below average			-96934	
GPM 16 to 17 MPG				-69512
GPM below 16 MPG				-69736
Adjusted R-squared	0.736	0.740	0.736	0.729

Table 4: Empirical Results for 2005 Model Year Vehicles

	Model 1	Model 2	Model 3
Intercept	-9765	-2289.7	-13983
Curb Weight	6.27***	6.08***	5.90***
Acceleration	-1384.0***	-1488.1***	-1450.6***
Turning Circle	275.1	291.0	243.2
Braking Distance	-56.0	-63.4	-38.4
Comfort Rating	4094.3	4059.9***	4162.1***
Comfort SUV/van	-1760.3***	-1702.0	-1730.4
Luxury	17,268***	17,453***	16,227***
Luxury SUV/van	-11,589**	-11572**	-9736*
Van	3530	3857	1992
SUV	7333*	7343*	6340
Cons. Rep. gallons/mile	131298**	-76967	210504***
GPM squared		1891341	
GPM for 16 to 17 mpg			249982
GPM for 18 to 19 mpg			372480
GPM for 20 to 22 mpg			45375
GPM for 23 to 25 mpg			255904
GPM for over 25 mpg			436722*
Adjusted R-squared	0.825	0.825	0.828

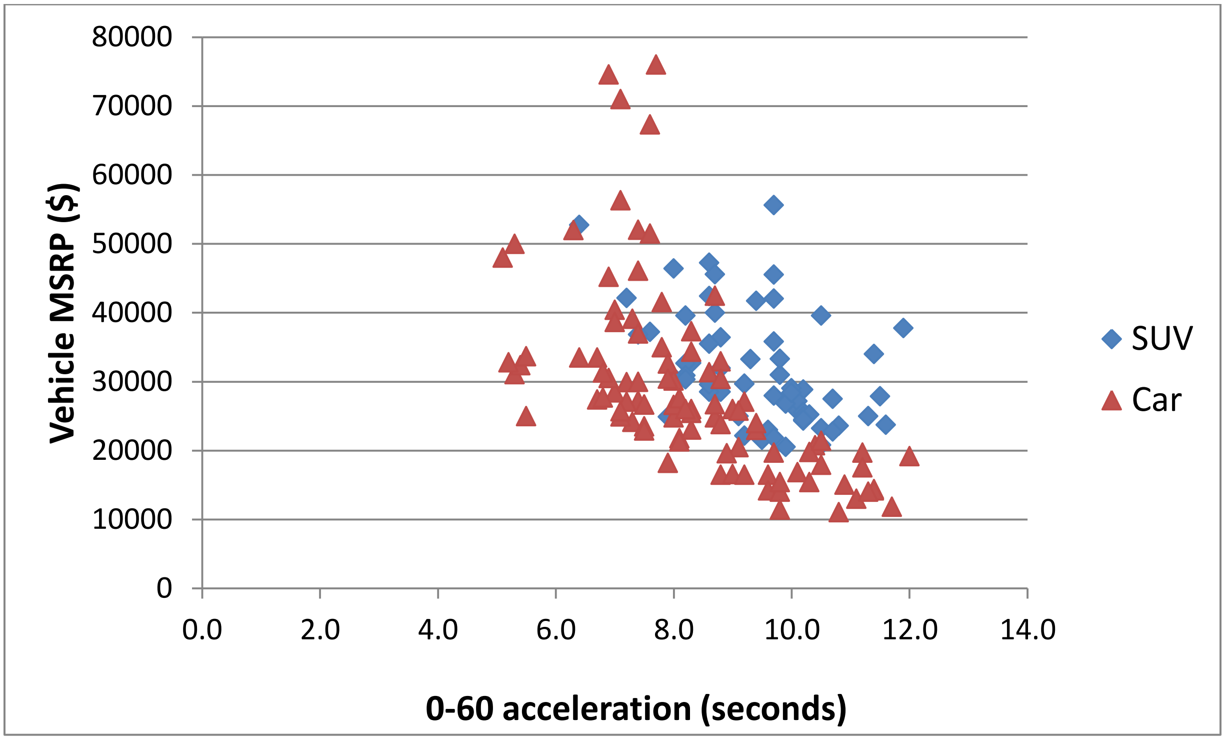

Figure 1: Vehicle Price and Acceleration

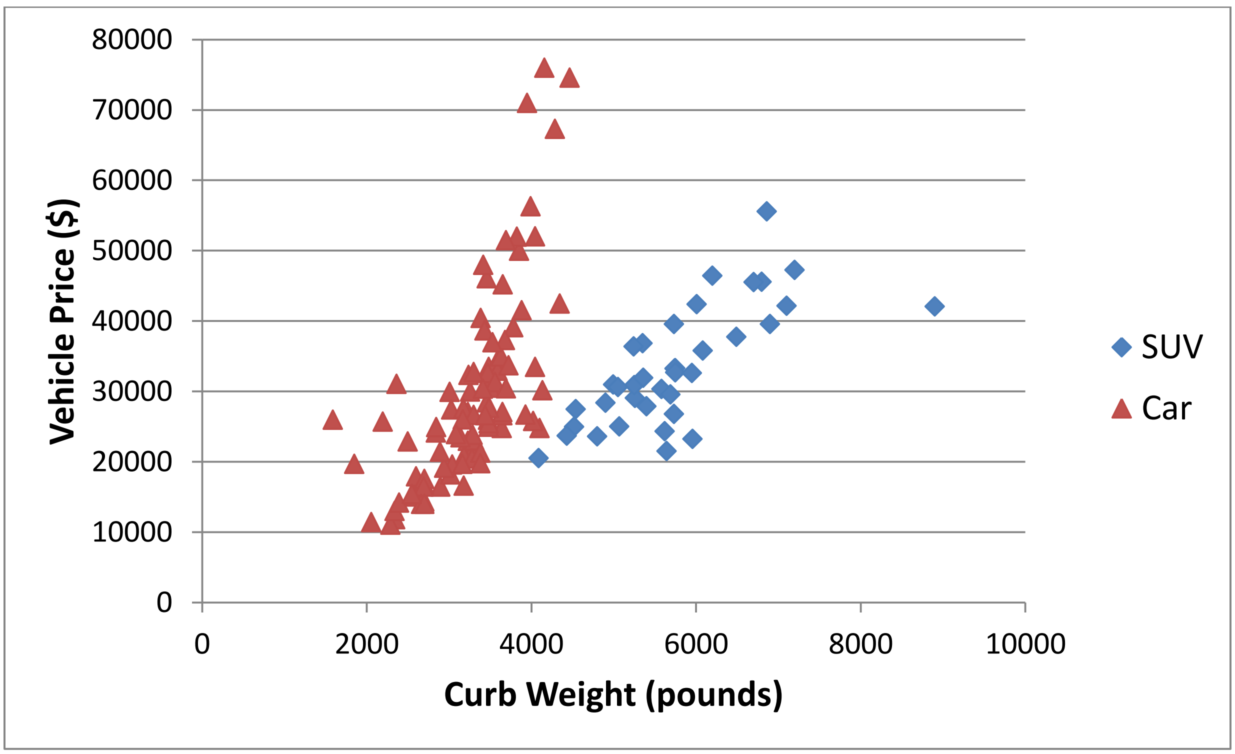

Figure 2: Vehicle Price and Curb Weight

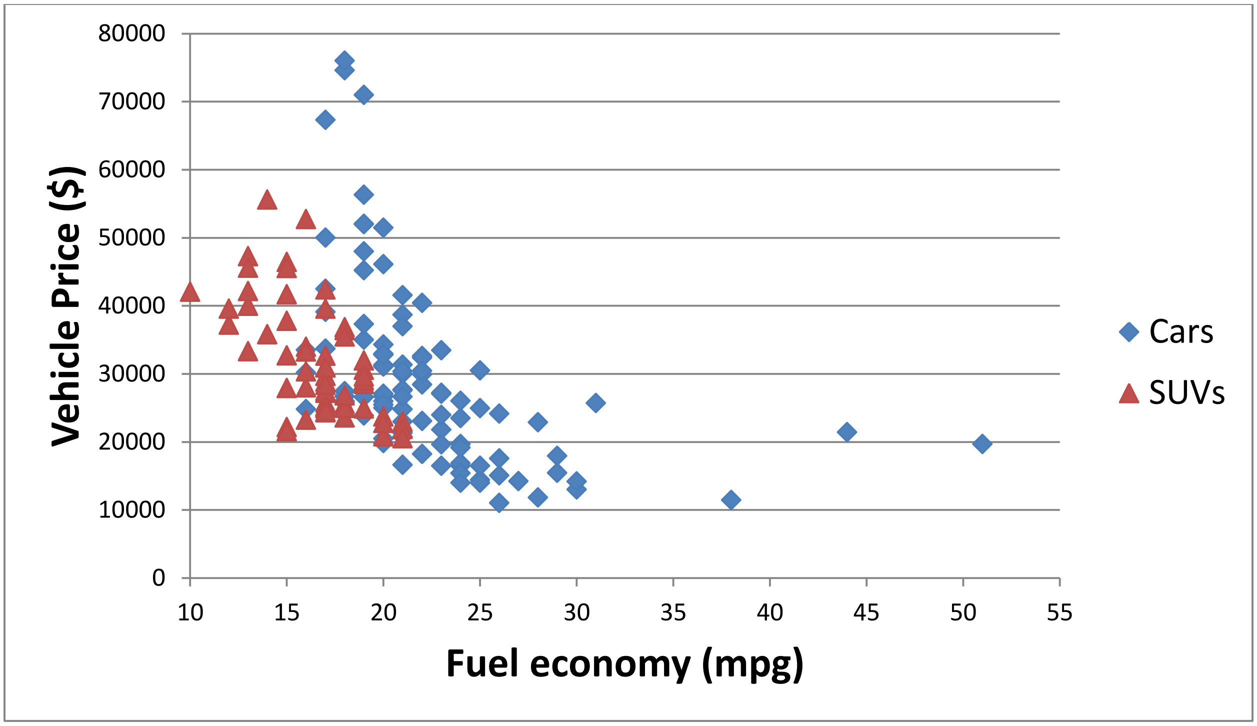

Figure 3: Vehicle Price and Fuel Economy