HOW CONSUMERS VALUE FUEL ECONOMY:

A LITERATURE REVIEW

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EXECUTIVE SUMMARY

Fuel economy or CO_2 emissions standards are a core component of governments' policy strategies to address global climate change and energy security. Standards have been adopted by the United States, the European Union, Japan and China, among others. The annual costs and benefits of these standards easily amount to tens of billions of dollars. How consumers' value future fuel savings in making car buying decisions has been shown to be a crucial determinant of the consequences of such standards for economic welfare (Fischer et al., 2007). Yet surprisingly little is known about this vitally important subject. This review examines empirical evidence from 28 econometric studies that directly or indirectly estimated the value consumers place on fuel economy.

The available econometric evidence is inconclusive. The 28 studies reviewed are approximately equally divided between those that imply that consumers significantly undervalue future fuel savings in their car buying decisions and those that find that they either approximately fully value or significantly over-value them. The studies span a wide range of model formulations, data sources, premises and estimation methods (Table ES-1). Yet there is no clear association between these distinguishing features and the conclusions reached by researchers. Furthermore, the econometric studies reviewed are, in general, technically well executed.

Because the estimates of consumers' willingness to pay for fuel economy improvements vary so greatly it would not be meaningful to try to identify a consensus value from the literature at the present time. Moreover, the appropriate theory of consumer decision making is also in doubt. Many of the studies reviewed assume that consumers follow the rational economic model: consumers make an estimate of future fuel prices, consider how long they will own a vehicle and how much driving they will do, calculate fuel savings per mile and, applying a discount rate, add up the present value of fuel savings over the life of the vehicle. Yet the little empirical evidence that exists about the fuel economy decision processes of actual consumers indicates that this model is very rarely used. The field of behavioral economics has recently provided a plausible alternative theory. Because future fuel savings are inherently uncertain, consumers will discount them heavily relative to certain initial costs. While this theory, referred to as loss aversion, is firmly established in behavioral economics, its application to decisions about fuel economy has only recently been proposed. At the present time, there is very substantial uncertainty about how consumers make decisions about fuel economy, as well as how much they value expected future fuel savings.

Of the 28 studies reviewed in this report, 25 can be used to derive estimates of consumers' willingness to pay for fuel economy improvements. Two of the studies by the same author are essentially the same, and two provide estimates of fuel price elasticities rather than the value of fuel savings, leaving 25 distinct estimates, explicit or implicit, of the value consumers attach to future fuel savings. The studies utilize a range of methods, including discrete choice models based on aggregate sales or disaggregate survey data, hedonic price models, asset price models and other methods. They are based on a wide range of data sources and cover varying time periods from 1970 to 2010. Ten of the studies are unpublished manuscripts, 13 are peer-reviewed journal articles and five are other published reports. In this author's opinion, there is no important difference in the quality of the analyses between the manuscripts or reports and the published journal articles.

Key findings of this literature review are:

1. Of the 25 distinctly different estimates, 12 studies indicate that consumers significantly undervalue future fuel savings relative to a reference values based on U.S. Department of Transportation data, 8 indicate that consumers' values are approximately equal to the reference expected value, and 5 indicate that consumers significantly overvalue fuel savings.
2. With a very few exceptions, there are no obvious flaws in the methods or data used by these studies. This finding applies equally to the published and unpublished studies.
3. There does not appear to be an obvious explanation for the widely divergent results. Neither model type, formulation of the variable representing fuel economy, data type, time period, nor any other readily identifiable factor shows a strong association with inferences about the values consumers place on fuel economy (Table ES-2).
4. Fifteen of the studies are based on some form of discrete choice model. These are evenly divided between under, equal and over-valuing fuel economy; studies using hedonic price, asset price and other models more often indicate undervaluing (Figure ES-1).
5. The studies are evenly divided between those dated 2008 or later (12) and those dated between 1994 and 2007. Six of the earlier studies and six of the 2008-2010 studies conclude that consumers significantly undervalue fuel economy. Seven of the earlier studies and six of the later studies imply that consumers roughly equally value or significantly over value fuel economy (Figure ES-2).
6. Consumers' expectations about future fuel prices are an important factor in all studies. Almost all of the studies assume that consumers will use the current price of fuel as a best estimate of future fuel prices, either due to static expectations or because they perceive fuel prices will follow a random walk. Five of the studies explore alternative price expectations models. However, none of the models allows consumers to project trends of increasing or decreasing prices into the future. Given the importance of price expectations to the evaluation of future fuel savings, a better understanding of how consumers form price expectations might provide useful insights.
7. Most of the studies (15) represent fuel economy as the price of fuel divided by miles per gallon, i.e., fuel cost per mile. These studies are evenly divided between undervaluing (5), equally valuing (5) and overvaluing (5) (Figure ES-3). Six included fuel economy without interaction with the price of fuel, either as miles per gallon or gallons per mile. Of these, five found undervaluing and one equally valuing. Four used a calculated discounted present value of future fuel costs based on assumptions about vehicle lifetime, usage and fuel price expectations to represent fuel economy. These studies were evenly divided between undervaluing and approximately equally valuing. These differences suggest that there may be some insights to be gained by testing hypotheses about whether consumers respond differently to fuel price changes as opposed to fuel economy differences, and whether responses to rising fuel prices differ from responses to falling fuel prices.
8. Several studies point out the empirical challenges to inferring the value of vehicle attributes to consumers, in general: (1) vehicle attributes such as weight, size,

performance, luxury and fuel economy are correlated, (2) there are important difficulties in defining and measuring the many relevant attributes of vehicles, and (3) there are important differences (heterogeneity) in tastes among consumers. These problems can lead to errors in variables and omitted variables and, together with correlations among variables they can result in seriously unstable, biased parameter estimates. More recent studies, exploiting massive data sets, have attempted to address these problems with detailed fixed effect coefficients formulations that recognize consumer heterogeneity and other methods. The persistent differences in results even among these studies suggest that even these efforts may not have successfully addressed the empirical challenges.

These findings are consistent with earlier literature reviews of implicit discount rates for fuel economy based on discrete choice models. The consistency with which the literature has yielded widely varying, inconsistent estimates over a period of more than three decades suggests that there is either a fundamental empirical problem in estimating the value consumers place on fuel economy, or that the presumed theory of consumer behavior is incorrect, or both. Recent but very limited in-depth survey evidence indicates that the rational economic model of consumer behavior is very likely not an accurate description of consumers' decision making about fuel economy.

Given the importance of understanding how the market values fuel economy and makes decisions about it, it might be worthwhile to convene qualified researchers with differing results to jointly investigate why those results differ so greatly. Such an effort would require sharing of data sets among researchers, who would then execute a mutually agreed upon set of statistical analyses, (1) to validate the results produced by others, and (2) to test a specified set of alternative model formulations using the different data sets. Such a structured test of model formulations against alternative data sets might lead to important insights about why apparently carefully and competently done analyses can lead to widely differing results.

It is at least as important to investigate the possibility that it is the rational economic consumer model that is incorrect. This line of inquiry might best be pursued in two steps. First, conduct more in-depth interviews, surveys and experiments, such as reported in the seminal paper by Turrentine and Kurani (2007), to discover what decision criteria and algorithms real consumers actually employ when considering fuel economy and valuing fuel savings. Second, test these alternative models using experimental methods and empirical market data.

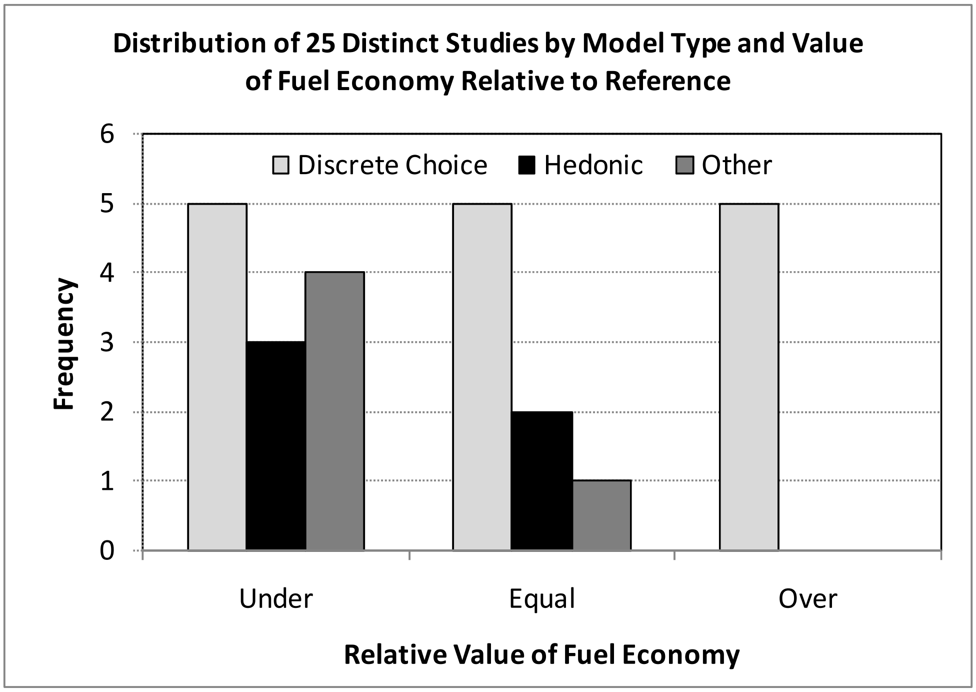

Figure ES-1. Distribution of 25 Distinct Studies by Model Type and Value of Fuel Economy Relative to the Reference Value.

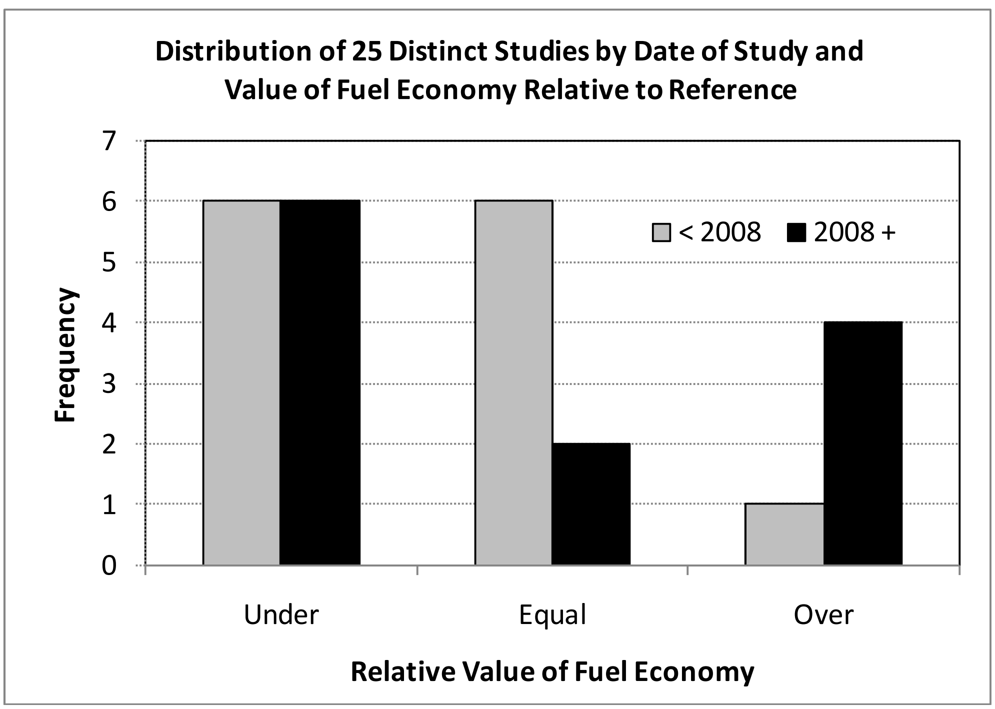

Figure ES-2. Distribution of 25 Distinct Studies by Date of Study and Value of Fuel Economy Relative to Reference Value.

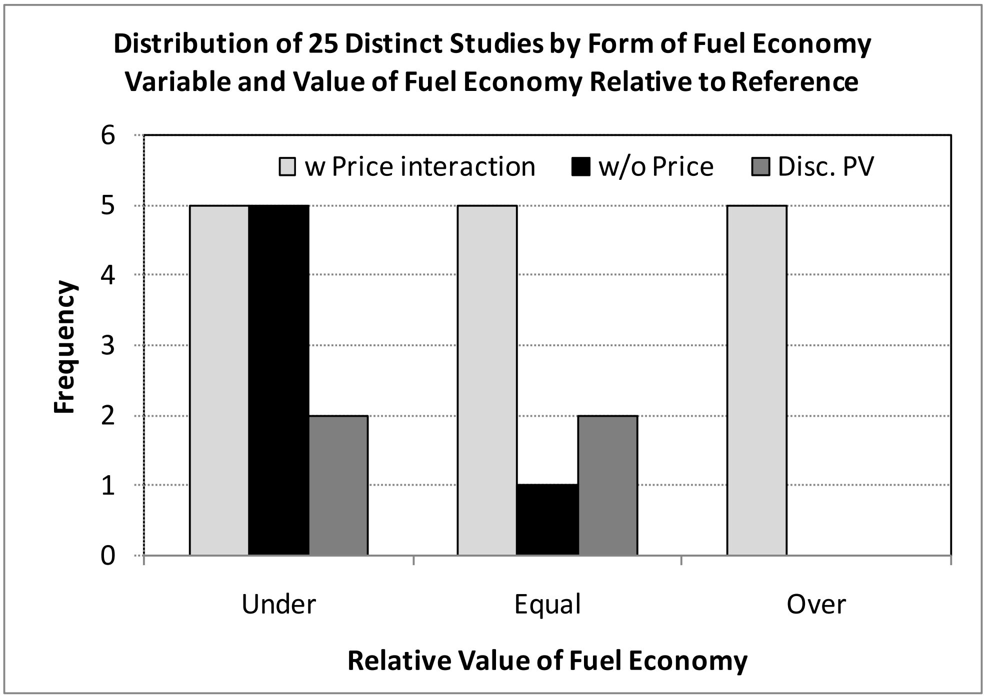

Figure ES-3. Distribution of 25 Distinct Studies by Form of Fuel Economy Variable and Value of Fuel Economy Relative to Reference Value.

Table ES-1. Summary of Consumers' Evaluation of Fuel Economy Improvements Based on 27 Recent Studies

Authors	Model Type	Data / Time	W-T-P as % of Discounted PV	Implied Annual Discount Rate
Alcott & Wozny (2009)	Mixed NMNL	Aggregate U.S., 1999-2008	25%	> 60%
Gramlich (2008)	NMNL	Aggregate U.S., 1971-2007	287% to 823%	
Berry, Levinsohn & Pakes (1995)	NMNL	Aggregate US, 1971-1990	<1% Non-significant	
Sawhill (2008)	Mixed NMNL	Aggregate U.S., 1971-1990	140%, range of -360% to 1,410%	
Train & Winston (2007)	Mixed NMNL	Survey, U.S., 2000	1.3% Non-significant	
Dagupta, Siddarth and Silva-Risso (2007)	NMNL	Survey, CA, 1999-2000		15.2%
Bento, Goulder, Henry, Jacobsen & von Haefen (2005)	NMNL	Survey, U.S., 2001	No direct estimate but MPG insensitive to price of gasoline	
Feng, Fullerton & Gan (2005)	NMNL	CES, U.S., 1996-2000	0.03% to 1.3%	
Klier and Linn (2008a)	Logit	Aggregate U.S., 1970-2007	Very approximately 69%	
Brownstone, Bunch & Train (2000)	Mixed NMNL Stated & Revealed Preference	CA Survey, 1993	132% to 147%	
Brownstone, Bunch, Golob & Ren (1996)	NMNL Stated & Revealed Preference	CA Survey, 1993	-420% to 402%	
Goldberg (1996, 1998)	NMNL	U.S. CES, 1984-1990	Consumers "not myopic"	
Goldberg (1995)	NMNL	U.S. CES, 1983-1987		
Vance & Mehlin (2009)	NMNL	Germany, Aggregate New Car Sales	Approximately 1,000%	
Cambridge Econometrics (2008)	Mixed logit	UK survey, 2004 to 2009	196% but uncertain of estimate. Authors contacted for clarifications.	
Eftec (2008)	NMNL	UK 2001 to 2006	TBD – authors contacted for clarifications.	
Fan & Rubin (2009)	Hedonic Price	State of Maine, 2007	Cars: 25% Lt. Trucks: 16%	Cars: 37% Lt. Trucks: 77%
Fifer & Bunn (2009)	Hedonic Price	U.S., 1996-2005	Cars: 52%, Pickups: 283% SUVs: 44%, Vans: 240%	
McManus (2007)	Hedonic Price	U.S., 2002	90%	
Espey & Nair (2005)	Hedonic Price	U.S., 2001	109%	
Arguea, Hsiao & Taylor (1994)	Hedonic Price	U.S., 1969 to 1986	3% to 46%	

Bhat & Sen (2006)	Choice model	San Francisco Bay Area, 2000	Elasticities of vehicle choice with respect to fuel costs 2% to 3% of purchase price elasticities.
Sallee, West & Fan (2010)	Price Regression	Aggregate U.S., Used Cars, 1978-2009	79%, not statistically different from 100%
Langer & Miller (2008)	Price Regression	U.S., 2003 to 2006	Approx. 15% of PV of fuel cost changes reflected in vehicle price changes.
Busse, Knittel & Zettelmeyer (2009)	Price Regression	U.S., 1999 to 2008	Transaction prices adjust by 1.2 years worth of fuel savings for new cars.
Kilian and Sims (2006)	Price Regression	Aggregate U.S., Used Cars, 1978-1984	11% to 25%
Li, Timmins & von Haefen (2009)	Vehicle sales by fuel economy quantile	U.S. Metro Areas 1997 to 2005	Short-run price elasticity of MPG with respect to sales mix +0.02, long-run +0.2.

Table ES-2. Summary of Key Features of 27 Econometric Studies

Study	Publication Status	Model	Dependent Variable	Type of Data	Time Period	Fuel Economy Measure	Price Expectations	Transaction Prices?	Heterogeneour Tastes?	Simultaneous Supply & Demand	Fuel Economy Standards Included?	MPG Value*
Berry, Levinsohn & Pakes 1995	Journal	NMNL	Sales shaes	Aggregate U.S.	1971-1990	Miles/P_g	Random Walk	No	Yes	Yes	No	—
Allcott & Wozny 2009	Manuscript	NMNL	New & used vehicle prices	Aggregate U.S.	1999-2008	Disc. PV of Fuel Cost	RW + alternatives	Yes	No	Yes	n.a.	—
Klier & Linn 2008	Manuscript	Logit	New vehicle shares	Aggregate U.S., monthly	1970-2007	Disc. PV of Fuel Cost	Random Walk	n.a.	Yes	No	No	0
Gramlich 2008	Manuscript	NMNL	New vehicle shares	Aggregate U.S.	1971-2007	P_g/MPG & MPG	Random Walk	No	No	Yes	Yes	+
Sawhill 2008	Manuscript	NMNL	New vehicle shares	Aggregate U.S.	1971-1990	Pg/MPG	ARIMA	No	Yes	Yes	No	+
Train & Winston 2007	Journal	Mixed Logit	Indiv. Vehicle Choices	U.S. Household Survey	2000	1/MPG	Static	No	Yes	Yes	n.a.	—
Dasgupta, Siddarth & Silva-Risso 2007	Journal	Mixed Logit	Indiv. Vehicle Choices	So. CA Vehicle Transactions	1999-2000	Pg/MPG	Static	Yes	Yes	No	n.a.	0
Bento, Goulder, Jacobsen & von Haefen 2005 & 2008	Journal	Random Coef. Logit	Indiv. Vehicle Choices	Nat. HH. Travel Survey U.S.	2001	Pg/MPG	Static	No	Yes	No	n.a.	X
Feng, Fullerton & Gan 2005	Manuscript	NMNL	Indiv. Vehicle Choices	CES	1996-2000	Pg/MPG	Static	No	No	Yes	n.a.	—
Brownstone, Bunch & Train 2000	Journal	Mixed Logit	Indiv. Vehicle Choices	CA survey	1993	Pg/MPG	Static	Yes, via respondents	Yes	No	n.a.	+
Brownstone, Bunch, Golob & Ren 1996	Journal	NMNL	Indiv. Vehicle Choices	CA survey	1993	Pg/MPG	Static	Yes, via respondents	No	No	n.a.	0
Goldberg 1995	Journal	NMNL	Indiv. Vehicle Choices	CES	1983-1987	Pg/MPG	Static	No	Yes	Yes	Yes	0
Goldberg 1996	Report	NMNL	Indiv. Vehicle Choices	CES	1985-1990	Pg/MPG	Static	No	Yes	Yes	Yes	0
Goldberg 1998	Journal	NMNL	Indiv. Vehicle Choices	CES	1984-1990	Pg/MPG	Static	No	Yes	Yes	Yes	0
Cambridge Econometrics 2008	Report	Mixed Logit	Indiv. Vehicle Choices	UK Survey	2005-2006	£/100 km	Static	No	Yes	No	No	+
eftec 2008	Report	Mixed Logit	Indiv. Vehicle Choices	UK Survey	2004 & 2007	l/100 km & £/100km	Static	No	Yes	No	No	—
Vance & Mehlin 2009	Report	NMNL	New Vehicle Shares	Sales data, Germany	1995-2007	€/100 km	Static	No	No	No	No	+
Fan & Rubin 2010	Manuscript	2-stage hedonic	New vehicle prices	Maine, sales data	2007	log(MPG)	Static	No	Yes	Yes	No	—
Espey & Nair 2005	Journal	1-stage hedonic	New vehicle prices	U.S. vehicle data	2001	1/MPG	Static	No	No	No	No	0
McManus 2007	Journal	1-stage hedonic	New vehicle prices	U.S. vehicle data	2002-2005	Pg/MPG	Static	Yes	No	No	No	0
Fifer & Bunn 2009	Thesis	1-stage hedonic	New vehicle prices	U.S. vehicle data	1996-2005	1/MPG	Random Walk	No	Yes	No	No	—
Arguera, Hsaio & Taylor 1994	Journal	2-stage hedonic	New vehicle prices	U.S. vehicle data	1969-1986	MPG	n.a.	No	No	Yes	No	—
Killian & Sims 2006	Manuscript	Asset Price	Used Car Prices	U.S.	1978-1984	PV fuel costs	Random Walk +	No	No	No	No	—

Table ES-2. Summary of Key Features of 27 Econometric Studies (continued)

Study	Publication Status	Model	Dependent Variable	Type of Data	Time Period	Fuel Economy Measure	Price Expectations	Transaction Prices?	Heterogeneour Tastes?	Simultaneous Supply & Demand	Fuel Economy Standards Included?	MPG Value*
Bhat & Sen 2005	Journal	MDCEV random utility	Individual vehicle choice	Survey: San Francisco, CA	2000	Pg/MPG	Static	Price not included	Yes	No	No	—
Langer & Miller 2008	Manuscript	Asset Price	New vehicle prices	U.S. regions weekly	2003-2006	Pg/MPG	Random Walk +	No	Yes	No	No	—
Busse, Knittel & Zettelmeyer 2009	Manuscript	Sales shares by quartile	New & Used vehicle prices	Sample, U.S. transactions	1999-2008	MPG Quartiles	RW	Yes	Yes	No	No	—
Li, Timmins & von Haefen 2009	Journal	Vehicle demand	Sales by Quantile	New & used sales in 20 U.S. metro areas	1997-2005	Pg/MPG & P_g	Random Walk	No	Yes	No	No	X
Sallee, West & Fan 2010	Manuscript	Asset Price	Used vehicle prices	Sample of U.S. auction transactions	1990-2009	Disc. PV of fuel costs	Random Walk +	Yes	Yes	No	No	0

* Indicates whether study generally implies that consumers undervalue (—), over-value (+) or equally value (0) fuel economy, or none of the above (X).

ABSTRACT

The extent to which consumers value the expected future fuel savings from fuel economy improvements to new passenger cars and light trucks is a key determinant of the levels of fuel economy achieved in unregulated markets and the effects of regulatory standards on consumers' surplus. This paper reviews 28 recent quantitative analyses of consumers' willingness to pay for automotive fuel economy. Some of the studies estimate discrete choice models with random or fixed coefficients, some are based on aggregate market data while others use disaggregate survey data. Other studies make use of hedonic price analysis or other methods. Their inferences about willingness to pay span a very broad range with roughly equal numbers finding significant under-valuing, significant over-valuing or approximately valuing the full present value of expected fuel savings over the lifetime of a typical vehicle. Although the methodologies or model formulations of a few of the studies are questionable, there do not appear to be clear associations among methods or data sources and the resulting inferences. It is suggested that such conflicting results may be attributable to the statistical problems caused by omitted variables, errors in variables and correlated variables, the complexity of consumers' vehicle choice decisions, and the likelihood that the rational economic consumer model does not adequately describe the decision-making of consumers in the real world. Additional, empirical behavioral research appears to be needed to resolve the issue.

1. INTRODUCTION

Passenger cars and light trucks account for 44% of the petroleum consumed in the United States each year and produce 16% of total U.S. greenhouse gas emissions (Davis, Diegel and Boundy, 2009, tables 1.13, 1.14, 11.3 and 11.7). Given the importance of the automotive sector to the U.S. economy, understanding the costs and benefits of fuel economy and greenhouse gas standards for light-duty vehicles is of great importance. The economic impacts of vehicle standards depend on the functioning of the market for fuel economy. In particular, carefully chosen regulatory standards have been shown to increase or decrease private welfare depending on how consumers value future fuel savings (Fischer, Harrington and Parry, 2007). The question has been controversial for decades, with some analysts assuming the market functions efficiently (e.g., Kleit, 1990; Austin and Dinan, 2005) while other assert that it does not (e.g., Greene, German and Delucchi, 2009). This paper surveys the recent literature of studies addressing consumers' willingness to pay for fuel economy improvements, trade-offs between capital costs and fuel costs, and related economic research. Despite a substantial body of significant new econometric evidence, the topic remains unresolved. In short, there is evidence supporting both sides and some in the middle, as well.

More than a quarter century ago, Greene (1983) reviewed the evidence on implicit consumer discounting of future fuel savings arising from the burgeoning literature in a new area of research applying discrete choice models to the problem of automobile choice.[1] Based on eight studies, Greene estimated implicit discount rates by assuming that consumers were trading off capital cost (vehicle price) and future fuel savings (mostly represented by fuel cost per mile). For all but one model, the implied discount rates ranged from 2% to 73% per year (Table 1).[2]

Greene summed up his findings as follows.

> "Eight recent studies are examined and estimates of asset price/operating cost discount rates are derived for each. A critical comparison of results suggests that most are implausible. Plausible estimates range from 4% to 40% as a function of household income." (Greene, 1983, p. 491)

In a comment to Greene's paper, Train (1983) suggested that the assumption that consumers are trading off capital and operating costs according to the model of rational economic behavior might be the problem.

> "There are many plausible reasons for believing that Greene's assumptions about consumer behavior are perhaps not correct. On the one hand, consumers might not be rational in their time allocation of money, in an economist's sense of the

[1] Discrete choice models typically estimate an indirect utility function, V(p,e,x), in which p is vehicle price, e is fuel use or fuel cost per mile. Discount rates can be estimated by noting that $-(\partial V/\partial e)/(\partial V/\partial p)$ is the implied value in dollars of a 1 unit change in e. Given assumptions about vehicle use over time, vehicle lifetime and the price of fuel, traditional discounting formulas can be used to estimate an implied discount rate.

[2] The model excepted, Manski and Sherman (1980), produced implied discount rates ranging from 2840% per year to -164% per year, depending consumers' on income and education levels.

> word "rational"….Given the difficulty my economics students have in calculating present values of future savings and holding costs for assets, I would not find this at all surprising." (Train, 1983, p. 498)

In light of subsequent research on how consumers actually consider fuel economy in their car buying decisions (Turrentine and Kurani, 2007), Train's comment appears to be prophetic.

Recent historically high fuel prices, combined with renewed interest in fuel economy and greenhouse gas emissions standards for automobiles have engendered a number of new assessments, many specifically aimed at understanding the effects of fuel prices and fuel economy on consumers' vehicle choices. This paper reviews those studies, published and unpublished, with the objectives of determining whether a consensus now exists on the value consumers place on fuel economy, and of gleaning insights into how consumers use fuel economy information in their car buying decisions. The intent of the review is to be comprehensive with respect to studies of the U.S. market for fuel economy that make inferences about consumers' willingness to pay for fuel economy improvements in both the new and used vehicle markets. A number of recent studies from the gray (not peer reviewed) literature are included because, in the authors judgment they are of publishable quality. There are so many of these studies and their quality is sufficiently high that, in the author's opinion, leaving them out would substantially reduce the value of the review. Unpublished studies are clearly indicated as such, however.

This review attempts to compare the inferences of different studies on a consistent basis: a typical consumer's willingness to pay for a reduction in the present value of fuel costs through improved fuel economy. This is never more than an approximation; however, since a variety of assumptions about vehicle use, consumer expectations and discount rates are necessary to make the calculation. In addition, consumers' behavior and preferences are heterogeneous due to different vehicle usage rates, and discount rates among other factors. Still, national averages provide a useful basis for comparisons. The assumptions used here are taken from the National Highway Traffic Safety Administration's (U.S. DOT/NHTSA, 2006) most recent assessment of vehicle usage and life expectancy, and are explained in detail in the appendix. In brief, the NHTSA analysis implies that passenger cars and light trucks in the United States can be expected to last 14 years, on average. Over 14 years, passenger cars are expected to travel 168,853 miles and light trucks 188,104 miles. Most studies assume that consumers expect fuel prices to follow a random walk, implying that the current price of fuel is the best predictor of future prices. That assumption is used here, as well, although there is little behavioral research to support it. If future fuel price is constant at the current level, then it is convenient to discount future miles traveled to present value, so that different values for fuel prices and fuel economy can be applied. Assuming a discount rate of 7% per year and discounting miles over the life of the vehicle results in 112,600 discounted lifetime miles for passenger cars and 125,891 miles for light trucks. These standard assumptions are used throughout the report to compare results from different studies. At the same time, it is recognized that consumers' preferences for fuel economy are heterogeneous, as several studies conclude.

Table 1. Estimated Unadjusted Discount Rates

1. Lave and Train (1978)

		Auto Price (1977$)		
		2500	3500	5000
Income	10,000	0.23	0.21	0.19
(1977$)	20,000	0.12	0.12	0.11
	25,000	0.10	0.10	0.09
	30,000	0.08	0.08	0.08
	50,000	0.05	0.05	0.05

2. Cardell and Dunbar (1980)
   Median = 0.43 Mean = 0.25

3. Beggs and Cardell (1980)

		Base Model	Financial and Size Variables Only
Household	10,000	0.59	0.73
Income	20,000	0.35	0.35
	25,000	0.31	0.31
	30,000	0.29	0.28
	50,000	0.24	0.23

4. Boyd and Mellman (1980)
   Simple logit 0.06
   Hedonic Median = 0.09 Mean = 0.02

5. Manski and Sherman (1980)

a) One-vehicle households

	Urban		Rural	
	Low I	High I	Low I	High I
College	0.10	0.06	0.18	0.19
No College	0.17	0.18	0.54	-0.16

b) Two-vehicle households

	Urban		Rural	
	Low I	High I	Low I	High I
College	0.64	0.09	-1.64	0.19
No College	28.4	0.26	-0.61	2.26

6. Beggs, Cardell and Hausman (1981)

	Common tastes		Individual tastes 0.30
	10,000	0.36	
	20,000	0.30	
Income	25,000	0.29	
	30,000	0.29	
	50,000	0.28	

7. Sherman (1982)
   One-vehicle households 0.13 [dependent on ln (miles annually) here 10,000]
   Two-vehicle households

		Annual Miles (both cars)		
		10,000	20,000	25,000
Income	10,000	0.02		
(1978$)	20,000	0.01	0.00	
	30,000	0.01	0.00	0.00

8. Train and Lohrer (1982)
   One-vehicle households
   0.12 if I ≤ 12,000 0.09 if I > 12,000
   Two-vehicle households
   0.12 if I ≤ 12,000 0.09 if 12,000 < I ≤ 20,000 0.05 if I > 20,000

Source: Greene (1983, Table 3)

This paper is organized as follows. Section 2 summarizes views of how the market for fuel economy functions, including both supply and demand. The body of the report is Section 3 which reviews recent empirical estimates of the value of fuel economy based on aggregate and disaggregate data, discrete choice models and hedonic demand analyses. Section 4 discusses the implication of those estimates and Section 5 contains concluding observations.

2. ALTERNATIVE MODELS OF CONSUMERS' EVALUATION OF FUEL ECONOMY

There is no doubt that consumers do care about fuel costs, do value fuel economy, and that their interest in fuel economy increases when fuel prices increase. Past evidence of this has been reviewed by Mahadi and Gallagher (2009) who also provide an analysis of the effects of gasoline price increases since 2000 on consumers' interest in fuel economy. The question is not whether consumers value fuel economy but how much? The issue is not whether the market for fuel economy responds to higher fuel prices but whether it responds efficiently. To be more precise, does the market value fuel economy improvements at society's discounted expected value of future fuel savings over the lifetime of a new vehicle, or significantly less or more? Fischer, Harrington and Parry (2007) have demonstrated that the answer to this question has profound implications for public policy concerning automotive fuel economy and carbon dioxide emissions. Considering only private costs and benefits, if consumers already fully value expected lifetime fuel savings, fuel economy standards lead to private welfare losses.[3] Studies that assume efficient markets inevitably arrive at this conclusion (e.g., Austin and Dinan, 2005). On the other hand, if consumers are myopic and consider only the first three years of fuel savings, for example, fuel economy standards can increase welfare even based solely on private costs and benefits.

Given the importance of fuel economy standards to manufacturers, consumers and society, it is surprising that there has been almost no behavioral research on how consumers consider fuel economy in their car buying decisions. Larrick and Soll (2008) found that measuring fuel economy in miles per gallon rather than gallons per mile leads to confusion about the value of increasing fuel economy. In general, consumers expect fuel savings to increase linearly with miles per gallon, leading to overvaluing of fuel economy increases for high MPG vehicles relative to lower MPG vehicles. Turrentine and Kurani (2007) conducted in-depth, semi-structured interviews with a stratified sample of 57 California households concerning the entire history of their car buying decisions. Their findings are well worth quoting at some length.

> "We found no household that analyzed their fuel costs in a systematic way in their automobile or gasoline purchases. Almost none of these households track gasoline costs over time or consider them explicitly in household budgets. These households may know the cost of their last tank of gasoline and the unit price of gasoline on that day, but this accurate information is rapidly forgotten and replaced by typical information. One effect of this lack of knowledge and

[3] Fischer, Harrington and Parry (2007) consider external costs as well as private costs in their study. The above comment pertains only to the private costs calculations in their report.

information is that when consumers buy a vehicle, they do not have the basic building blocks of knowledge assumed by the model of economically rational decision-making, and they make large errors estimating gasoline costs and savings over time.

"Moreover, we find that consumer value for fuel economy is not only about private cost savings. Fuel economy can be a symbolic value as well, for example among drivers who view resource conservation or thrift as important values to communicate. Consumers also assign non-monetary meaning to fuel prices, for example seeing rising prices as evidence of conspiracy. This research suggests that consumer responses to fuel economy technology and changes in fuel prices are more complex than economic assumptions suggest." (Turrentine and Kurani, 2007, p. 1213)

Turrentine and Kurani's final observation, that consumers' fuel economy decision making is more complex than any single economic model, echoes Train's (1983) observation and is important to keep in mind as one reviews the empirical studies of vehicle choice and fuel economy. Very likely, there is not one correct model or one correct set of parameters waiting to be discovered. Instead, the goal should be to find a useful generalization of a set of complex behaviors that likely vary from one individual to another, perhaps bearing little resemblance to the model of perfectly rational economic behavior.

2.1 SUPPLY SIDE

Although the functioning of the supply side for fuel economy is not the central focus of this review, appropriately representing the supply of fuel economy is important both for understanding how the market functions, as well as for estimating models of fuel economy demand. There are three key issues: (1) the competitive structure of the industry, (2) the nature of short- and long-run supply responses, and (3) the effect of regulatory standards versus market decisions on fuel economy.

Most econometric studies of the U.S. market assume the industry is an oligopoly (e.g., Bento et al., 2005; Berry, Levinsohn and Pakes, 1995; Goldberg, 1995; Austin and Dinan, 2005; Busse, Knittel and Zettelmeyer, 2009). For example, Eftec (2008, p. vi) considered the United Kingdom (UK) automobile market to be a non-collusive oligopoly, characterized by a relatively small number of manufacturers all of whom take account of the actions of the others in making product and pricing decisions. Goldberg modeled the U.S. automobile industry as an oligopoly with multiproduct firms. Goldberg (1998) assumed that domestic and imported manufacturers formed two groups, within which there was collusion but between which there was Bertrand competition. However, she notes that this assumption was based on computational constraints rather than on observation of actual business practices.

The globalization of the world economy raises doubts about the characterization of the U.S. auto market as an oligopoly. There are now approximately 25-30 significant vehicle manufacturers in the global marketplace, not considering partial ownership of one firm by another. Although all these firms are not now participating in the U.S. market, the barriers to entry are not great.[4] With this many firms participating and relatively low barriers to entry, it may be more appropriate to characterize the current and future supply side as monopolistically competitive. In a monopolistically competitive market, firms sell differentiated products and strive to capture rents thereby, but in the long run products sell at their long-run average costs, and normal rates of profit prevail. This assumption is consistent with profit rates observed in the industry in recent years (Rogozhin, Gallaher and McManus, 2009).

Manufacturers' ability to respond to changes in consumer demand for fuel economy or regulatory standards differs depending on the length of time available (NRC, 2002; Klier and Linn, 2008). In the short run (less than two years) manufacturers can change the prices of vehicles to induce shifts in sales and make very minor changes to vehicles themselves (e.g., tires, lubricants, engine control algorithms). Within 2-7 years, manufacturers will have an opportunity for major design changes to every vehicle they produce. In general, vehicles are redesigned over a 4-5 year cycle, with 20% to 25% of any given manufacturer's product line being redesigned each year in order to evenly distribute capital investments and use of engineering expertise. Engine and transmission lines are typically amortized over a somewhat longer period, on the order of 10 years. Studies vary in the degree to which they take account of these cycles of change.

For studies that attempt to estimate the demand for fuel economy taking into consideration the simultaneous effects of supply and demand, it is critically important to recognize the impacts of fuel economy regulations. Although there is some disagreement about the relative effectiveness of the Corporate Average Fuel Economy Standards versus market responses to the price of gasoline (e.g., see NRC, 2002; Gerard and Lave, 2003; Greene, 1990), there can be no doubt that the standards had a major impact on the level of fuel economy observed in the market (Figure 1). Failure to recognize fuel economy constraints on manufacturers is likely to seriously bias estimates of consumers' willingness to pay for fuel economy especially in hedonic price regressions where identification of the demand function is a critical issue. Some studies do explicitly incorporate fuel economy constraints while others do not.

[4] Chief among these are certification to U.S. safety and environmental standards. Even in these respects there is increasing harmonization in world markets.

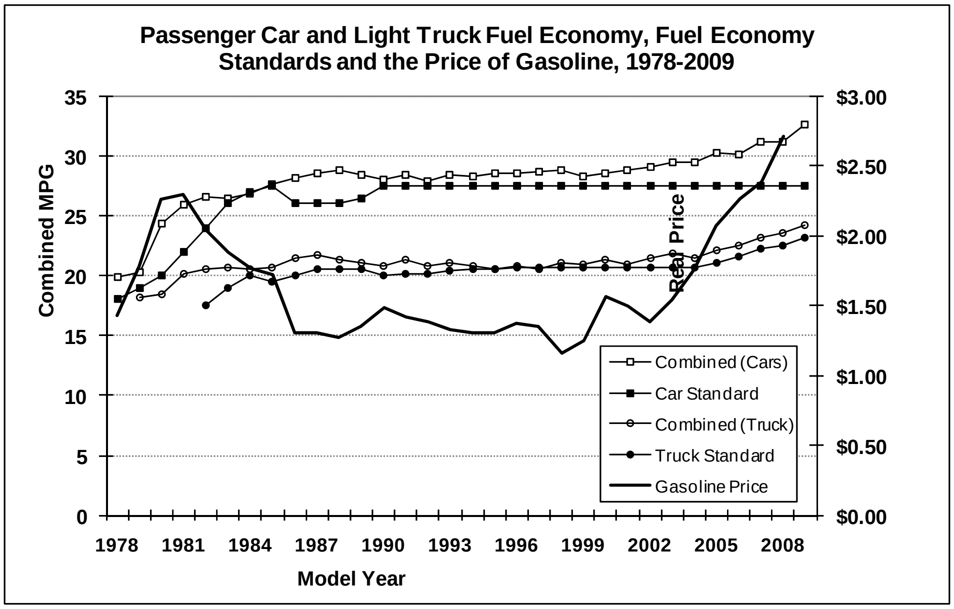

Figure 1. Passenger Car and Light Truck Fuel Economy, Fuel Economy Standards and the Price of Gasoline, 1978-2009.

2.2 DEMAND SIDE

While there is no doubt that consumers respond to fuel prices and value fuel economy to some degree, there is also little doubt that very few consumers compare discounted present values of fuel costs when making vehicle choices. Turrentine and Kurani's (2007) research demonstrates only that the strict, rational economic model of consumer behavior probably does not apply to consumers' decision making about fuel economy.[5] By itself, this does not tell us whether consumers under- or over-value fuel economy. There is still the possibility that consumers approximate an efficient market response based on experience and intuition.

Some analysts contend that the market for fuel economy reasonably approximates a perfectly competitive market from the demand side. For example, Austin and Dinan (2005) assume that consumers fully value lifetime fuel savings when considering fuel economy in their vehicle choices.

> "We argue, though, that there is no such market failure – that the information on new-vehicle window stickers, reporting the EPA's city and highway mileage rating and the vehicle's estimated annual fuel cost, is sufficient to allow consumers to make informed decisions about fuel economy." (Austin and Dinan, 2005)

[5] This finding is definitive for the 57 households in their study. However, it cannot necessarily be extrapolated to the United States as a whole because the households are from only California and were selected by a stratified random sampling method. Turrentine and Kurani defined 10 household types of interest and then randomly selected six households in each group. In addition, gasoline prices were relatively low when the surveys were conducted.

Consumers make decisions that involve present capital cost and future energy costs in many areas and behavioral researchers have voiced doubts about the efficiency of markets for energy efficiency for decades (e.g., Stern and Aronson, 1984). Economic analyses of consumer choices of other types of energy using equipment have produced estimates of implicit discount rates that are several times average rates of return on capital (Allcott and Wozny, 2009; Hausman, 1979; Train, 1985; Howarth and Sanstad, 1995; U.S. DOE/EIA, 1996, table 3). A variety of explanations have been proposed for the apparent undervaluing of energy savings by consumers, ranging from irrationality and imperfect information to the rational assessment of the value of waiting in a market in which energy prices are generally rising but highly uncertain (Hassett and Metcalf, 1993). Energy analysts have identified several types of market failures[6] that affect the market for energy efficiency (e.g., Howarth and Sanstad, 1995; ACEEE, 2007):

- Principal agent conflicts
- Information asymmetry
- Transaction costs
- Bounded rationality
- External costs and benefits

With the exception of externalities, there is little quantitative evidence of the impact of these failures on consumers' choices of energy using durable goods (ACEEE, 2007).

Two recent analyses have quantified the potential impacts of uncertainty and risk or loss adverse behavior on the market for fuel economy. Delucchi (2007) quantified the uncertainty in the key elements of the fuel economy decision, and by assuming consumers would make uniformly conservative estimates for each factor, demonstrated that the resulting decisions would appear to reflect a high discount rate for future fuel savings. For example, consumers with a real discount rate of 5.5% would appear to have a discount rate of 19% if they conservatively estimated factors such as the life of the vehicle, lifetime vehicle miles, the price of fuel, and the fuel economy that would be realized in actual use (in distinction to the official fuel economy rating).

Greene, German and Delucchi (2009) and Greene (2009) applied the theory of context dependent loss aversion from behavioral economics to the question of valuing fuel economy and concluded that a typically loss averse consumer would behave as if he or she required a simple 3-year payback for increased fuel economy. Their method quantified uncertainties about realized in-use MPG, fuel price, vehicle life expectancy, annual miles of travel, and the cost of increased fuel economy in order to derive a probability distribution of present value rather than a single number. Because the net present value is the difference of savings-cost, there is a chance the consumer will lose money on the deal. By applying loss aversion functions derived by Tversky and Kahnemann (1992) they showed that a 25% improvement in passenger car fuel economy that had an expected present value of +$400 would be perceived by loss averse consumers to have a present value of -$30. A potentially significant aspect of the theory of loss aversion is that it is context dependent and allows consumers to undervalue fuel economy at the time of the purchase

[6] In the author's view, the term "market failure" is unfortunate because it implies an inability to perform a function rather than the impairment of a function. Market perfection is a high standard indeed and it is doubtful that any market fully satisfies the criteria for rational economic decision making (Rubenstein, 1998). What matters then is how far the market for energy efficiency is from an efficient solution. This requires quantification.

decision but fully value fuel savings afterward. While these calculations are based on empirical data, there has been no testing of the theories either via experiments with consumers or by statistical inference from market transactions.

3. LITERATURE REVIEW: VALUE OF FUEL ECONOMY

This section reviews 27 recent empirical studies that produced quantitative inferences about the value of fuel economy to consumers. Helfand and Wolverton (2009) provide a qualitative analysis of the recent literature, and raise most of the issues considered here. The studies reflect a wide range of data sources, model formulations and estimation methods. Approximately half of the research reviewed has been published in refereed journals, however, most of the recent research which takes advantage of the very large fuel price increases in 2008, is found in unpublished manuscripts. In this reviewer's opinion, the quality of the unpublished research is equal to that of the published research.

The studies have been grouped into five categories:

1. Discrete choice random utility models using aggregate data
2. Discrete choice random utility models using disaggregate survey data
3. Discrete choice models using non-U.S. data
4. Hedonic price regressions
5. Asset price models

Of these studies, twelve generally indicate that consumers significantly undervalue fuel economy, nine conclude that consumers value fuel economy at approximately its discounted present value of future fuel savings (three are very similar papers by the same author), and four find that consumers significantly over-value fuel economy. There is no clear association between a study's findings and its choice of model, data source, or estimation method. It is suggested that this may be attributable to the complexity of vehicle choices which lead to very difficult problems for statistical inference, combined with the likelihood that the rational economic consumer model may be an inappropriate representation of consumers' fuel economy decision making.

3.1 DISCRETE CHOICE MODELS

3.1.1 Aggregate Data

In a seminal paper, **Berry, Levinsohn and Pakes (1995)** develop a new method for estimating both demand functions with random coefficients and cost functions, based on aggregate sales data for over 2,000 makes and models of vehicles over the period 1971-1990. The model assumes a utility function that is linear in the logarithm of u, in which y is the income of consumer I, p_j the price of vehicle j, X is a vector of observed attributes of vehicle j, v a fixed effect, ε_{ij} a random error, and the term in summation the sum of cross products of unobserved vehicle and consumer attributes.

$$u_{ij} = \alpha\, log\big(y_i - p_j\big) + X_j\beta + v_j + \sum_k \sigma_k x_{jk} v_{jk} + \varepsilon_{ij} \tag{1}$$

Because prices are endogenously determined in their model, Berry, Levinsohn and Pakes (1995) estimate the consumer utility functions using instrumental variables.

Fuel economy enters the consumers' utility function not as miles per gallon but as miles per dollar, MPG divided by price per gallon (more precisely, the variable is the number of ten mile increments one could drive for $1 worth of gasoline). This formulation accounts for the very substantial variations in the price of gasoline over the 1971 to 1990 period. However, it also implies a linear relationship between increasing fuel economy and utility. This is less than ideal because fuel economy is the inverse of fuel consumption and fuel expenditures are linearly related to fuel consumption. Representing fuel economy by miles per dollar with a constant marginal utility parameter implies that consumers purchasing vehicles with higher levels of fuel economy place a higher value on the same quantity of fuel savings than purchasers of vehicles with lower levels of fuel economy. This makes it all the more surprising that the authors' analysis of elasticities shows decreasing elasticity of vehicle choice with respect to miles/$ with increasing miles/$.

> "The elasticity of demand with respect to MP$ declines almost monotonically with the car's MP$ rating.
>
> "Hence we conclude that consumers who purchase the high mileage cars care a great deal about fuel economy while those who purchase cars like the BMW 735i or Lexus LS400 are not concerned with fuel economy." (Berry, Levinsohn and Pakes, p. 878)

Berry, Levinsohn and Pakes find that the average value of fuel economy (MP$) is not significantly different from zero, regardless of whether the scale of production of each vehicle is included in the equation or not. On the other hand, the variance of the value of fuel economy is statistically significant. The estimated parameters of the authors' preferred model are shown in Table 2. The average values of the coefficient estimates for MP$ are negative, implying that more miles per dollar is undesirable, but are not close to being statistically significant. This result, which will appear again in the random coefficient mixed logit model of Train and Winston (2007) implies that while some car buyers value fuel economy as a positive attribute others find it to be a negative factor. On average, the market is approximately indifferent.

Table 2. Estimated Parameters of the Demand and Pricing Equations:
Berry, Levinsohn and Pakes' Specification, 2,217 Observations

Demand Side Parameters	Variable	Parameter Estimate	Standard Error	Parameter Estimate	Standard Error
Means ($\bar{\beta}$'s)	Constant	-7.061	0.941	-7.304	0.746
	HP/Weight	2.883	2.091	2.185	0.896
	Air	1.521	0.891	0.579	0.632
	MP$	-0.122	0.320	-0.049	0.164
	Size	3.460	0.610	2.604	0.285
Std. Deviations (σ_β's)	Constant	3.612	1.485	2.009	1.017
	HP/Weight	4.628	1.88	1.586	1.186
	Air	1.818	1.695	1.215	1.149
	MP$	1.050	0.272	0.670	0.168
	Size	2.056	0.585	1.510	0.297
Term on price (α)	ln (y – p)	43.501	6.427	23.710	4.079
Cost Side Parameters	Constant	0.952	0.194	0.726	0.285
	ln (HP/Weight)	0.477	0.056	0.313	0.071
	Air	0.619	0.038	0.290	0.052
	ln (MPG)	-0.415	0.055	0.293	0.091
	ln (Size)	-0.046	0.081	1.499	0.139
	Trend	0.019	0.002	0.026	0.004
	ln (q)			-0.387	0.029

Source: Berry, Levinsohn and Pakes (1995, table IV)

Because of the inverse relationship between miles per dollar and fuel expenditures ($/mile) the value of fuel economy in the Berry, Levinsohn and Pakes' model varies with both the price of gasoline and the level of MPG. Berry, Levinsohn and Pakes report an average value of 20.86 miles per 1983 $ for their sample. The average price of gasoline from 1971 to 1990 in 1983 dollars was $1.03 per gallon (U.S. DOE/EIA, 2009, table 5.24), thus the average fuel economy of cars in the sample was 20.2 miles per gallon. Since the average value of MP/$ is negative (implying fuel economy is a bad) it is more interesting to calculate the value of fuel economy to consumers whose attribute value is one standard deviation above the mean.

$$\frac{\partial u}{-\partial MP\$} \Big/ \frac{\partial u}{\partial P} = \frac{(-0.122+1.050)}{-0.0435} = 21.33 \left(\$/_{MP\$} \right) \tag{2}$$

Since MP$ is in units of tens of miles per dollar, the value of a 1 mile per dollar increase in fuel economy is $2.13. Using the standard assumptions for discounting future fuel savings described in the appendix, the present value of a 1 MPG increase from 20 MPG to 21 MPG would be $254. Thus, even consumers who are interested in fuel economy appear to be undervaluing it by roughly two orders of magnitude.

U_{ij} = utility of vehicle choice j to consumer i
$u_{ij} = \log[U_{ij}]$
P_j = price of vehicle j
X_j = a vector of attributes of vehicle j
Y_i = income of consumer i
Z_i = a vector of characteristics of consumer i that may interact with the attributes of vehicles
β = a parameter vector of mean consumer utility values for vehicle attributes indexed k = 1, n
σ = a vector of variances for consumers' values of vehicle attributes, k = 1, n
ε_{ij} = a random utility parameter varying across consumers and vehicle choices
ν_i = a vector of unobserved components of utility varying across vehicle choices

The stability of parameter estimates for models like the random coefficient logit model of Berry, Levinsohn and Pakes (1995) has been studied in depth by Knittel and Metaxoglou (2008). The objective function optimized to estimate the coefficients of such models is generally highly nonlinear, and thus prone to multiple, local optima. One of the data sets analyzed by Knittel and Metaxoglou was the automobile choice data base of Berry, Levinsohn and Pakes (1995). They tested 10 different optimization algorithms, using 50 different starting values for each. Their findings call for caution not only in estimating such models, but in interpreting any set of estimated parameters.

> "We find that convergence may occur at a number of local extrema, at saddles and in regions of the objective function where the first-order conditions are not satisfied. We find own-and cross-price elasticity estimates that differ by a factor of over 100 depending on the set of candidate parameter estimates." (Knittel and Metaxoglou, 2008)

Allcott and Wozny (2009) estimated a nested logit discrete choice model using an extensive data set of both new and used vehicles up to 25 years old in use in the United States between 1999 and 2008. The central purpose of their analysis is to test whether the effect of a $1 change in the price of a vehicle is the same as the effect of a $1 change in the discounted present value of fuel costs. Their estimating equation is derived from the consumer's utility function in the nested logit framework.

$$p_{jat} = -\alpha G_{jat} - \beta ln(s_{jat}) + \gamma ln(s_{jat}/s_{nt}) + \delta_{ja} + \phi_t + \varepsilon_{jat} \qquad (3)$$

In equation (3) p_{jat} is the price of model j of age a, in year t, G is the discounted present value cost of future gasoline use, s_{jat} is the market share of model j, and s_{nt} is the market share of the nest to which vehicle j belongs. The log ratio of market shares enters the equation due to the nested logit structure which allows differing price effects within nests and across nests. The constants δ and ϕ are fixed effects representing, respectively, the other attributes of model j of age a, and shifts in the desirability of the outside good from year to year. Finally, ε_{jat} is a random error term. The random error term is assumed to be uncorrelated with G, while the model and age fixed effects (δ_{ja}) can be correlated with G. Because of the simultaneity of vehicle prices and market shares, equation (3) is estimated using instrumental variables and two-stage least squares.

Calculating the discounted present value of fuel costs requires a number of assumptions including expectations about future fuel prices. Allcott and Wozny's approach was to choose assumptions that were supported by credible data and that were biased towards accepting their null hypothesis.

> "We formulate our assumptions to conservatively bias us against finding that consumers undervalue gasoline costs. We find, however, undervaluation for any plausible set of assumptions about gasoline cost expectations, vehicle survival probabilities, vehicle miles traveled, and other parameters. We conservatively estimate that U.S. auto consumers are willing to pay only twenty-five cents to reduce expected discounted gas expenditures by one dollar." (Allcott and Wozny, 2009, p. 5)

For example, the authors assumed that consumers would discount future fuel costs at 15% per year; if this discount rate is too high, the present value of fuel costs will be understated and the leverage of fuel costs on market shares will be overestimated. This is consistent with their intent to bias their analysis in favor of finding that consumers fully value or overvalue fuel economy. Used vehicle prices came from a data base of auction prices that tracks 5 million transactions annually. New vehicle prices came from a data base of 2.5 million new vehicle transaction prices.

Under a wide variety of model formulations and assumptions, Allcott and Wozny found that consumers substantially undervalue future fuel costs in their choices of new and used vehicles. The preferred form of their nested logit model, using instrumental variables to account for potential simultaneous equations bias, produced an estimate of 0.25 for the ratio of the coefficient of present value fuel costs to that of vehicle price. This implies that consumers count a present value dollar of fuel costs as only $0.25 relative to a dollar of purchase price. The nested logit estimated by ordinary least squares (OLS) produced a ratio of 0.15, while the simple (un-nested) logit generated an estimate of 0.33 and a simpler reduced form model yielded a ratio of 0.23. Testing the sensitivity of the results to alternative nesting structures, Allcott and Wozny found a range of estimates from 0.22 to 0.35.

Alternative assumptions about gas price expectations produce a range of estimates for the value of $1 present value of fuel costs of $0.20 to $0.46. Although Alcott and Wozny's models of consumers expectations span a range from random walk to the use of NYMEX futures prices, there is still no consensus as to which of the alternatives, if any, accurately represents the way consumers form their expectations about future fuel prices. At the same time, this is a critical element in the analysis. These sensitivity tests suggest that the inference that consumers underweight fuel costs relative to purchase price in both new and used car purchase decisions is relatively robust. Increasing the assumed discount rate used to calculate the present value of fuel costs (in the preferred nested simultaneous model) drove the ratio closer to one, as expected. At an assumed 60% annual discount rate, the estimated ratio was 0.74, still lower than 1.0 implying that consumers are using an even higher discount rate.

The undervaluing of fuel economy found by Allcott and Wozny is very large relative to vehicle prices and the cost of fuel. It suggests a very serious departure from the rational economic consumer model. The authors conclude that correcting this market imperfection would increase the privately optimal level of fuel economy by 9 miles per gallon by sales mix shifts alone. They also conclude that the market failure of undervaluing fuel costs is even more significant than externalities associated with fuel use.

> "Comparing these figures shows that the welfare gains from reducing negative externalities are dwarfed by the welfare gains from reducing the "internality" by inducing consumers to make the *privately*-optimal choice. Perhaps the most important take-away from this analysis then is that behavioral misoptimization can be a more powerful justification for fuel economy policies than internalizing environmental externalities." (Allcott and Wozny, 2009, p. 33)

Klier and Linn (2008) use a data base of new vehicle sales covering an unusually long time period from 1970 to 2007 by detailed model and model year to estimate the effects of fuel price changes on vehicle sales. They do not directly estimate a measure of willingness to pay, nor can one be derived from their model without making a number of important assumptions. Nonetheless, their model does indicate a relative insensitivity of vehicle sales and fleet average fuel economy to fuel price. Their analysis is entirely focused on the effect of fuel economy on sales of different makes and models and the impact of those salesmix changes on average fuel economy. It does not address changes in vehicle technology, engineering or design made by manufacturers to improve fuel economy. The paper also does not address the impacts of the Corporate Average Fuel Economy (CAFE) standards on sales or fuel economy.

The form of their model is similar to that used by other studies. The utility, U_{ijt}, of vehicle model j, within a given model year, to individual I, in month t is assumed to be the sum of services flows from observed, X_j, and unobserved, ω_j, vehicle attributes and the cost of obtaining those services, which is the sum of the vehicle's purchase price, P_j, maintenance costs, m_j, and fuel costs, f_{jt}.

$$U_{ijt} = \alpha\left(P_j + m_j + f_{jt}\right) + X_j\beta + \omega_j + \varepsilon_{ijt} \tag{4}$$

In equation (4) α and β are coefficients to be estimated and ε_{ijt} is a random error. The form chosen for equation (4) allows a model-specific intercept to be defined as the sum of all the components that vary only over j, that is everything except the cost of fuel and the error term. Assuming the error term has the extreme value distribution; the share of model j will be a logit function of its fuel costs, those of other models and the attractiveness of the outside good, which is assumed to be an arbitrary used vehicle. The difference between the log market share of model j and the log market share of the outside good is given by the following.

$$ln\left(s_{jt}\right) - ln(s_{Ot}) = \alpha f_{jt} + \phi_j \tag{5}$$

In equation (5), ϕ_j is a model specific constant measuring the relative value of model j in comparison to the outside good (used car) except for the effect of fuel costs on the market share of j. To eliminate the used car share from equation (5) the authors add dummy variables to time periods and index ϕ_{jy}, by model year, y. Like others, they specify fuel costs as the discounted present value, but assume that the price of gasoline follows a random walk, so that the expected price is equal to the current price.

$$ln(s_{jt}) = \alpha \left[\sum_{s=t}^{T+t} \frac{1}{(1+r)^s} \frac{p_t}{MPG_{jy}} M_s \right] + \delta_t + \phi_{jy} + e_{jt} = \acute{\alpha} \frac{p_t}{MPG_{jy}} + \delta_t + \phi_{jy} + e_{jt} \tag{6}$$

Note that the coefficient α' now includes α times discounted lifetime miles. It should therefore be possible to approximately recover the original α by dividing by an appropriate estimate of discounted lifetime miles. However, this would give the value of fuel costs in utils per dollar. One would need a purchase price coefficient to convert to dollars of present value fuel cost per dollar of purchase price, and this model does not have one. While it would be possible to assume a purchase price coefficient based on other studies, the uncertainty would be great since price coefficients vary substantially from study to study. However it may be useful to try and bound the implications of Klier and Linn's analysis. In the logit model framework they use, the coefficient of purchase price (b) is the following function of a vehicle's market share (σ), its own price (P), and the own price elasticity of its market share (β).

$$b = \frac{\beta}{P(1-\sigma)} \tag{7}$$

In general, with hundreds of models available in any given model year, σ for any given model will be negligible, so that the price slope is chiefly a function of the own price elasticity and own price. For a typical car, an average price is approximately \$20,000 to \$25,000, and a reasonable range for model level price elasticities is -2 to -6. Using an average price of \$25,000, this produces a range of price slope estimates from -0.00008 to -0.00024, with a midpoint value of -0.00016. Klier and Linn's overall estimates of α' range from -10 to -15 (Klier and Linn, 2008a, table 2). Applying our estimate of discounted miles for a passenger car of 112,600, produces a range for α of -0.0000888 to -0.000133, with a midpoint of -0.000111. Recall that this α is the coefficient of expected lifetime fuel costs. Dividing α by the purchase price slope gives 0.69, implying that a new car buyer would be willing to pay \$0.69 for a reduction in expected lifetime operating costs of \$1. However, given the number of assumptions required to arrive at this estimate, all that it is meaningful to say is that its general magnitude is plausible. Klier and Linn also estimate individual coefficients for each model in their sample. The estimates range from -65 to +35, following a skewed distribution with a mode around -15 (Figure 2). Like other studies that allow for heterogeneity, Klier and Linn find very substantial heterogeneity in consumers' apparent valuation of future fuel savings.

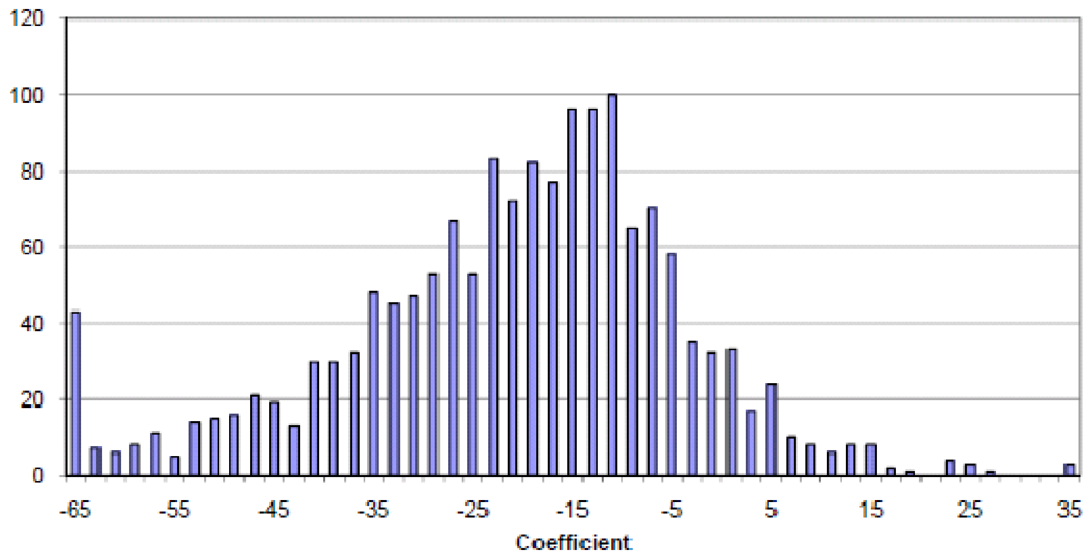

Figure 2. Histogram of Estimated Coefficients of Dollars per Mile from Klier and Linn (2008).

Gramlich (2008) proposed a model of U.S. automobile supply and demand in which manufacturers decided on the level of fuel economy to include in vehicle designs by trading off increased fuel economy against increased cost and a measure of quality. New car demand is represented by a nested logit model, estimated using U.S. sales data for 1971-2007. Consumer i is assumed to choose the vehicle model (j) that maximizes utility. Utility is a function of vehicle price (p_j), fuel economy ($econ_j$), other quality ($qual_j$), which "…includes things such as power, weight, acceleration, electronics, sportiness, interior room, etc. – in short, the collection of other vehicle attributes that must be traded off with fuel efficiency." (Gramlich, 2008, p. 6). Other variables common to all vehicles in a given year, such as macroeconomic factors, and vehicle specific fixed effects are also included.

Gramlich makes the important observation that the correlation of fuel economy with other vehicle attributes creates estimation biases.

> "Previous models, including seminal work, have had difficulty finding parameter estimates that show consumers care about fuel efficiency. Parameters on preference for fuel efficiency have been biased towards zero. The reason for this is that in automobiles, fuel efficiency (MPG) is negatively correlated with other characteristics that provide utility. Some of these characteristics are observed and easily controlled for, such as horsepower and weight. Others, however, are not." (Gramlich, 2008, p. 4)

Surprisingly, the measure of *quality* selected by Gramlich was precisely fuel economy in miles per gallon. The idea is that fuel economy will represent *negative* quality, that is, it will represent the trade-off between fuel economy and quality. The positive value of fuel economy is represented by the price of fuel divided by miles per gallon.

> "Fuel efficiency (MPG) affects both the fuel economy (econ) and "other quality" (qual) of a vehicle through the technological tradeoff. …The measure I use for

> qual is MPG itself. This may seem unusual but, conditional on the economic effects of fuel efficiency (dpm), higher MPG is strongly associated with lower "other quality." (Gramlich, 2008, p. 7)

This formulation raises two questions. The first is whether fuel economy is an adequate (negative) proxy for quality. The numerous excluded dimensions of quality include not only factors that are clearly negatively related to fuel economy, such as size, power, and energy using accessories, but also items seemingly unrelated to fuel economy, such as reliability, fit and finish, and safety features. Indeed, the two manufacturers with the highest fuel economy given the mass and power of their passenger cars are Toyota and Honda, manufacturers also having among the highest reputations for quality (Knittel, 2009). Thus, using MPG as the sole proxy for quality would seem to create problems of omitted variables and errors in variables, conditions likely to lead to biased estimates. It is highly unlikely that MPG itself could serve solely as a negative proxy for other quality attributes and not in any way function as a positive attribute itself. The formulation also requires that any increase in fuel economy necessitates a reduction in quality in other areas. That is, does not permit fuel economy to be purchased at a higher price without degrading quality.

The second issue is that using fuel price divided by MPG does not allow for distinction between consumers' valuation of fuel economy versus their reaction to changes in gasoline prices, since the effects are constrained to be equal and opposite effect. Although a presumption of rational behavior implies that the effects of price and fuel economy should be equal and opposite, this hypothesis can be tested and, indeed, that should be one of the objectives of an analysis of the effect of fuel economy on consumers purchase decisions. Including MPG by itself as a measure of quality also confuses the interpretation of price/MPG.

Another difficulty with Gramlich's model formulation is that he assumes that decisions regarding the designs of vehicles are taken the year before the current model year. This does not match the consensus understanding of how vehicle designs are changed over time. According to the NRC (2002) report on the Corporate Average Fuel Economy standards, manufacturers typically lock in vehicle designs two years in advance to allow time for tooling, certification and testing. In addition, only about 20% of a manufacturer's makes and models are substantially redesigned in any given year, in order to allow more efficient use of engineering resources and to distribute capital expenditures more evenly over time. Gramlich (2008) does test two alternative formulations with 3 and 5 year lags in design, but neither reflects the continuous, gradual redesign process manufacturers follow in reality.

Gramlich (2008) calculated willingness to pay for an increase in MPG from 25 to 30 miles per gallon. With gasoline at $2/gal., luxury car purchasers were willing to pay $4,098, compact car owners were willing to pay $7,377 and SUV owners $11,749. If the price of gasoline increased to $3.50, luxury car owners would pay up to $7,172, compact car owners $12,910 and SUV buyers, $20,560. These values are high relative to the discounted present value of fuel savings. Using the standard assumptions of this assessment, an improvement in fuel economy from 25 to 30 MPG is worth $1,428 present value, with gasoline at $2/gal. and $2,500 with gasoline at $3.50/gal.

Gramlich also used his model to make predictions about the impact of the increases in gasoline prices from 2007 to 2008 on the average fuel economy (identical to fuel efficiency in the quote below) of new light-duty vehicles and on vehicle sales.

> "To check the predictive ability of the model, I compare out-of-sample predictions to 2008 actual figures. The model matches sales composition changes well. Actual aggregate sales are down 12% through August from 2007 levels, compared to a prediction of 11.9%. The model also predicts an increase in sales-weighted fuel efficiency of 28%, a number consistent with the large 2008 reductions in purchases of SUVs and light trucks." (Gramlich, 2008, p. 4)

Indeed, according to U.S. EPA (2009) data, sales of passenger cars and light trucks declined from 15.277 million units in model year 2007 to 13.900 million units in model year 2008, a reduction of 9.0%, quite close to Gramlich's model's prediction. The average fuel economy of new light-duty vehicles increased from 25.8 to 26.3 MPG (combined, unadjusted test value), a change of only +1.9%. Using the city MPG measure Gramlich used in his model estimation, the increase was from 21.8 to 22.1, or +1.4%. Fleet average MPG numbers reported by the NHTSA (U.S. DOT/NHTSA, 2009) are very similar to the EPA numbers: 27.0 for 2008 versus 26.6 for 2007, an increase of 1.5%. Thus, while Gramlich's model did a reasonable job of predicting the decline in vehicle sales it was off by more than an order of magnitude in over-predicting the impact of higher fuel prices.

Sawhill (2008) estimated a model to quantify the trade-off between automobile operating cost and purchase price using a virtually identical data base (1971-1990 model years) and a very similar methodology to Berry, Levinsohn and Pakes (1995). The key differences are that Sawhill's model includes heterogeneous consumer preferences and explicitly represents expectations about future fuel prices. Vehicle prices are list prices, although they are assumed to be endogenously determined along with unobserved vehicle attributes and operating costs are represented by the price of gasoline divided by fuel economy. The authors do not state so explicitly, but given the source and the data shown in their table 2, the fuel economy data is almost certainly the EPA adjusted, combined MPG measure. Consumers' expectations about future fuel prices are based on an autoregressive model in price differences fitted to annual historical gasoline price data. This implies that consumers form an analogous model via observation of fuel price changes. The coefficient of the lagged price difference is 0.35 in the expectations model, indicating that the change from last year is expected to persist, with a rapidly declining rate. The author states that fuel cost is used as a proxy for vehicle operating cost, asserting that fuel costs are the largest share of operating costs. However, no other future costs (e.g., insurance, maintenance and repairs, etc.) are included in the model. According to data from the publication *Motor Vehicle Facts and Figures* (Davis, Diegel and Boundy, 2009, table 10.14) depreciation and financing costs are about 56% of the total costs of owning and operating a motor vehicle. The issue is whether fuel costs are truly a proxy for all costs paid out over time, as opposed to vehicle purchase price, or whether the other costs should be considered one of the many unobserved vehicle attributes. If fuel costs are a proxy for (and therefore correlated with) other future costs, then one might expect the coefficient of fuel costs to be biased upwards. If non-fuel future costs are more correctly interpreted as unobserved attributes, then the coefficient of fuel costs could be unbiased.

The key equation of Sawhill's model relates consumer i's utility for automobile j to the price of vehicle j, the expected present value operating cost of j over the car's lifetime, and vectors of observed (x_j) and unobserved (z_j) attributes of vehicle j, as well as a random error term, ε_{ij}.

$$U_{ij} = -\alpha_i \left(p_j + \gamma_i E(c_{ij})\right) + \boldsymbol{x}_j^T \boldsymbol{\beta}_j + z_j + \varepsilon_{ij} \tag{8}$$

The parameter α represents consumer i's sensitivity to price (or income) while a value of γ different from 1 indicates that consumers value fuel savings differently from purchase price. $E(c_{ij})$ is a key function representing the consumer's expected present value of future operating costs. For γ to equal 1, $E(c_{ij})$ must be measured accurately. This requires that price expectations be accurately represented. It also requires that fuel economy and the distribution of annual miles be correctly estimated. Sawhill uses data from the Department of Energy's 1991 RTECS survey to estimate the distribution of vehicle miles. Data for all model years rather than just new vehicles were used but mileage was adjusted by a weighting factor intended to represent the frequency of new vehicle purchases for each car as a function of its annual mileage. Vehicles were assumed to be driven different numbers of miles per year by different households but to all have the same total lifetime miles. This is clearly not the case, but it is also not correct to assume that all vehicles last for the same number of years. Thus, the expected life of a vehicle is an inverse function of annual use equal to the average lifetime miles divided by the household's annual mileage. Based on the adjusted RTECS data an estimated average lifetime mileage of 90,000 was used (p. 15). The expected annual miles driven for a typical new car in Sawhill's study is 13,612. At this rate the vehicle's expected life would be 6.6 years. These numbers are far lower than the reference lifetime mileage estimates used by the Department of Transportation (DOT): 152,137 miles for passenger cars and 179,954 for light trucks (U.S. DOT/NHTSA, 2006), based on expected lifetimes of just over 13 years for passenger cars and 14 years for light trucks (see appendix). The fuel cost calculation also assumes an annual real discount rate of 5% for the base model. Finally, consumers are able to adjust their annual driving rates as fuel prices increase or decrease, although sensitivity testing showed that this factor had a minor influence on the estimated coefficients.

Sawhill (2008) first estimates a simple model that includes neither heterogeneous consumer preferences nor price expectations. The OLS and two-stage least squares versions of the simple model imply that consumers undervalue the discounted present value of future fuel savings. In contrast, versions of the full model including heterogeneity of consumers' preferences and price expectations indicate that most consumers overvalue fuel costs (representing operating costs) by a factor of about 1.4. A ratio of 1.0 would imply that consumers equally value a dollar change in vehicle price and a dollar change in the expected present value of lifetime fuel savings. Increasing average lifetime mileage to 110,000 from 90,000 miles reduced the ratio to 1.3. Increasing the expected lifetime miles to 152,137 would presumably bring the ratio closer to 1. The estimated variability of valuation of fuel costs is considerable; a 95% confidence interval for the distribution of fuel costs in the population is -3.6 to 14.1. This implies that some consumers prefer higher fuel costs but this could be a consequence of the assumed symmetrical distribution of consumer preferences.

The only vehicle attributes included in the base model formulation were horsepower, a measure of car size whose average varies from 1.5 to 1.25 over the sample period, and air conditioning. As a test of robustness to the specification of vehicle attributes, the authors also estimated a model including a dummy variable for an automatic transmission, the number of cylinders in the vehicle's engine and the number of doors in the vehicle. Including these variables has little effect on the coefficient of price, which changes from -3.78 to -3.64. The coefficient of fuel costs, however, changes from -5.26 to -3.27. The standard deviation of the fuel cost coefficient measuring its distribution in the population also changes from 4.5 to 2.8. While these are not dramatic changes they do indicate a nontrivial sensitivity of the estimated fuel cost coefficient to both the included variables and the specification of the present value of fuel costs.

Because Sawhill's model is focused on fuel costs as a proxy for operating costs, it is not possible to separate the influence of fuel economy from that of fuel price expectations on consumers' car buying decisions. It may be that consumers respond differently to fuel price changes and changes in fuel economy that produce equivalent changes in expected present value operating costs. Different influences for fuel economy and fuel price have been found in econometric analyses of vehicle miles of travel, for example (e.g., Small and Van Dender, 2007; Greene, 2010).

3.1.2 Survey Data

Train and Winston (2007) formulated a mixed logit choice model that allows the estimation of average values, values that vary systematically with consumer attributes, and values that are randomly distributed in the population. They estimated the model using a random sample of 458 U.S. consumers who acquired a 2000 model year vehicle. The consumer data included the make and model of the vehicles they purchased, other vehicles they seriously considered, their vehicle ownership histories and socioeconomic characteristics. They found that the effect of fuel consumption (gallons per mile) in the average utility equation, was negative as expected but not statistically significant. The estimated coefficient was reported to be -0.0032 with a standard error of 0.0023. Fuel consumption was not included in the estimation of utilities that varied across consumers as a function of consumers' socioeconomic attributes. There was a statistically significant component that varied randomly across the population, comprised of the coefficient -0.0102 (std. err. = 0.0020) times a standard normal random variable N(0,1). This implies that about 62% of the respondents considered lower fuel consumption (higher fuel economy) to be a positive attribute for a new vehicle while about 48% considered it to be a disadvantage. On average, consumers considered better fuel economy to be slightly, and not statistically significantly, advantageous. Taking the value -0.0032 at face value and using the standard assumptions for fuel cost and vehicle use, a 0.01 gal./mi. change in fuel consumption (equivalent to 20 MPG to 25 MPG) would be worth only $30 to the average consumer. Using the reference assumptions about vehicle use, lifetime, a 7% real annual discount rate and gasoline at $2/gallon, an improvement to 25 MPG should be worth $2,250 to owners of a typical passenger car, and $2,500 to the owner of a light truck

Dasgupta, Siddarth and Silva-Risso (2007) estimated a mixed logit model of consumers' choice of vehicle and lease-buy option using data from vehicle transactions in Southern California for the period September 1999 to October 2000. Only 15 vehicle models were included in the study, all were in the entry-luxury market segment. Although the contract choice equation included fuel cost per mile as a variable, the structure of the model is such that its coefficient should be interpreted as the distribution of annual miles traveled. The authors report the estimated mean of that distribution as 16,380 miles with a standard deviation of 1,914 miles. Although this prohibits estimating an implied discount rate from the ratio of the net price (net present value of acquisition costs) and fuel cost coefficient, consumers' implicit discount rates were inferred from consumers' choices among purchase and leasing options. The structure of the model implies that the discount rate for lease or loan payments should be the same as the discounting of future fuel costs. The authors report an estimated discount rate of 15.2%, higher than the 9% annual market rate prevailing at the time the transactions occurred. The inference that this is the discount rate for future fuel savings also depends on the accuracy of the average annual mileage estimate of 16,380.

Bento, Goulder, Henry, Jacobsen and von Haefen (2005) estimated a model of vehicle choice and use using data from the 2001 National Household Travel Survey, augmented with data on vehicle attributes and operating costs. They estimated a random coefficient model of households' vehicle and vehicle travel choices. Although estimated coefficients and mean values of some variables are available in an extended on-line version of the paper (Bento et al., 2008; http://www4.ncsu.edu/~rhhaefen/auto051808.pdf) the information is not sufficient to estimate trade-off rates between fuel economy and rental cost. The model's estimates of the impacts of higher gasoline prices on vehicle travel and vehicle fuel efficiency shed some light on how consumers value fuel economy. Although it is not explicitly discussed in the paper, the fuel economy impacts presumably come about via consumers' choices among a fixed set of vehicles and do not include manufacturers' decisions about the technological content and design of vehicles. Their estimates of the impacts of gasoline price increases of $0.10, $0.30 and $0.50 per gallon over a base price of $1.45 per gallon (6.9%, 20.7%, and 34.5%), in cases with and without income-based revenue recycling are shown in Table 3. The change in MPG is very small, ranging from 0.04% (0.01 MPG) for the $0.10 increase without revenue recycling to 0.24% (0.06 MPG) for the $0.50 per gallon increase with revenue recycling. Implied elasticities of MPG with respect to fuel prices are shown in parentheses.

Table 3. Impacts of Gas Tax Increases Calculated by Bento et al. (2005)

	Base	$0.10	$0.30	$0.50
Fuel Price	$1.45	+6.9%	+20.7%	+34.5%
MPG no recycling	24.2	+0.04%	+0.11%	+0.18%
		(+0.006)	(+0.005)	(+0.005)
MPG with recycling	24.2	+0.05%	+0.13%	+0.24%
		(+0.007)	(+0.006)	(+0.007)

Bento et al., 2005, table 1.

Feng, Fullerton and Gan (2005) estimated a simultaneous model of vehicle use and choice of ownership using data from the 1996 to 2000 Consumer Expenditure Survey. The detail on vehicle type was limited to passenger car or SUV, and only households owning 1, 2 or no vehicles were included. A nested multinomial logit model structure was assumed, however, the requirement for simultaneous estimation of vehicle use and ownership choice required a two-stage estimation method. There are six fuel cost per mile coefficients in their model: (1) single car or first car in two-car household, (2) second car in two car household, (3) single SUV or first SUV in two-SUV household, (4) second SUV in two SUV household, (5) car in car+SUV household, and (6) SUV in car+SUV household. Four of the six estimated coefficients of vehicle capital cost and fuel cost per mile were statistically significant and all had appropriate negative signs. The coefficients, their ratio to the coefficient of capital cost, the implied value of a $0.01 per mile change in fuel cost per mile, and that value as a percent of the full lifetime discounted present value of a $0.01 per mile change in operating costs are shown in Table 4. For estimation, Feng et al. (2005) represented capital costs in units of thousands of dollars and they state that they represented fuel cost per mile in units of dollars per mile (table 6 and p. 6). As seen in Table 4, the estimated willingness to pay for reduced fuel cost per mile is on the order of 1% of the discounted present value of lifetime value. If Feng et al. actually converted fuel cost per mile in dollars per mile to fuel cost per mile in cents per mile but did not report that in their paper, then the values of fuel costs implied by their model's estimates would be comparable to lifetime discounted present value.

Table 4. Estimated Value of Fuel Costs in Vehicle Ownership Choice Model of Feng, Fullerton and Gan (2005)

Variable	Coefficient Estimate	Implied Value $/Unit	Willingness to Pay as a % of Lifetime Discounted PV
Only Car/1st Car	-0.433	-1069	1.0%
2nd Car	-0.045	-111	0.1%
Only SUV/2nd SUV	-0.526	-1299	1.0%
2nd SUV	-0.013	-32	0.03%
Car in Car/SUV HH	-0.399	-985	0.9%
SUV in Car/SUV HH	-0.662	-1635	1.3%

Source: Feng, Fullerton and Gan (2005, table 7). The coefficient of capital cost in dollars rather than 1,000s of dollars is -0.000405. Discounted lifetime miles are 112,600 for cars and 125,891 for SUVs.

An additional interesting finding of Feng et al.'s study was that coefficient estimates varied considerably depending on the estimation method used.

Brownstone, Bunch and Train (2000) estimated a mixed logit choice model for automobiles using a combination of stated and revealed preference data. Use of stated preference data was necessary in order to include in the choice set alternative fuel vehicles, such as battery electric and compressed natural gas vehicles, which were generally unavailable in the market at the time. The data base was a multi-wave survey that began with a telephone survey of 7,387 California households carried out in 1993. Households were not only asked about the vehicles they owned, but about vehicles they intended to purchase, if any. A total of 4,747 households completed a more detailed mailed questionnaire. Households to whom a questionnaire was mailed were also contacted by phone and asked about their preferences for alternative fuel vehicles. More than a year after the above surveys were completed, most of the original households were re-interviewed. Of these, 874 had purchased a vehicle and these became the revealed preference data set for the logit model estimation. In the end, there were two stated preference and one revealed preference observation for each of these households.

First, models were estimated using the stated and revealed preference data sets separately. In the preferred stated preference mixed logit model, fuel economy entered as the denominator of fuel cost per mile. The coefficient of fuel cost per mile was negative and statistically significant, as expected. Vehicle price entered as price in thousands of dollars, divided by the natural logarithm of household income in thousands. The mean of log(income) was 4. The average willingness to pay for fuel cost reduction is therefore: -(-0.236/((-0.503/1000)/4)) = $1,877 per penny per mile change in fuel cost per mile. The normalized coefficient estimates also provided by Brownstone et al. in their table 2 indicate a willingness to pay of $1,710 for a 1 cent decrease in fuel cost per mile. Using the standard assumptions about lifetime miles (112,600 discounted lifetime miles for passenger cars, 125,891 for light trucks), a one cent per mile change in fuel costs would be worth $1,126 for passenger cars and $1,259 for light trucks, indicating that in the stated preference survey consumers tend to overvalue lifetime fuel savings. However, the value of fuel cost per mile has a large variance, which led Brownstone et al. to make the following observation.

> "Unfortunately, the relatively large error component for operating cost implies that the model will generate an (implausible) positive price effect for one third of the respondents." (Brownstone et al., 2000, p. 327)

The willingness to pay in Brownstone et al.'s (2000, tables 3 and 4) revealed preference model is even greater, $2,240 per 1 cent per mile. The mixed logit model estimated on the combined stated and revealed preference data indicated a willingness to pay for reduced fuel cost per mile of $1,660.

Brownstone, Bunch, Golob and Ren (1996) estimated a nested logit choice model of household ownership and use that included modeling of vehicle acquisition and disposal transactions. The data came from a stated preference survey of California urban households conducted in June and July of 1993. Households were asked to choose among hypothetical vehicles that included alternative fuel vehicles. Choice models were estimated for households owning one and two vehicles. Both the vehicle price (in dollars) and operating cost (in cents per mile) coefficients were varied according to income, the presence of children in the household and ownership of a luxury vehicle. Estimates of the willingness to pay for a reduction in fuel cost per mile for these groups are shown in Figure 3. There is a wide range of implied willingness to pay, with only about four out of the ten estimates being close to our reference willingness to pay estimates of $1,126 per penny per mile for passenger cars and $1259 for light trucks. The greatest willingness to pay ($4,718) was for households with incomes of more than $30,000 per year, no luxury vehicle but with children in the household. The lowest value was -$4,526 for households with incomes exceeding $75,000 per year and no children.

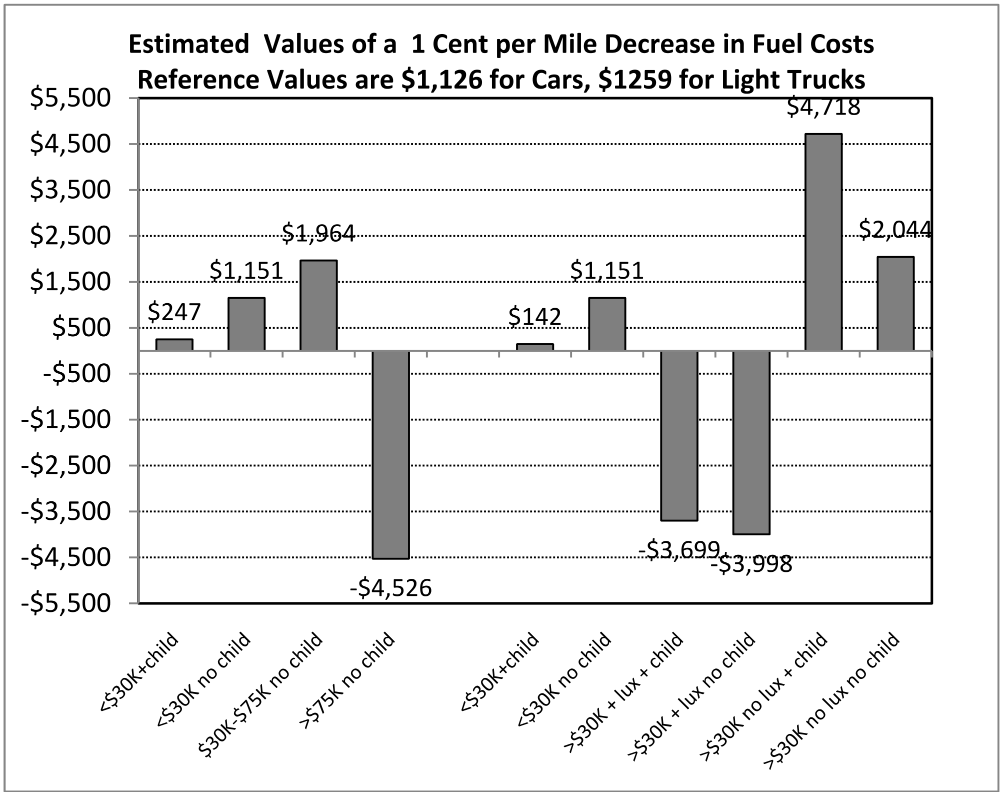

Figure 3. Estimated Values of a 1 Cent per Mile Decrease in Fuel Costs Based on Brownstone, Bunch, Golob and Ren (1996, tables 3 and 4).

Goldberg (1995) estimated a nested multinomial logit model of consumers' choices among passenger car and light truck makes and models. Three equations of make and model choice were estimated using pooled data from the 1983 to 1987 Consumer Expenditure Surveys: (1) small cars comprised of subcompacts and compacts, (2) luxury automobiles including sports cars, and (3) all other vehicles. A likelihood ratio test rejected the hypothesis that the three classes of vehicles had the same coefficient values. Fuel efficiency was represented by the regional price of gasoline times the rate of fuel consumption in gallons per mile, i.e., fuel cost per mile. In the small car choice equation, fuel cost per mile was decidedly statistically significant; the coefficient of -7.143 being almost ten times its standard error. The coefficient estimate of fuel cost per mile in the "Big Car" equation, -1.381, was only 1.86 times its standard error, making it significant at the 10% but not the 5% level. In the luxury vehicle equation fuel cost per mile had the wrong sign (+0.231) but was not close to being statistically significant.

Calculating the value of fuel economy using Goldberg's (1995) results is uncertain because she is not precise about the units used when estimating her model. The variable definition for price, for example is purchase price and vehicle specific dummy variables, and while the mean values shown in her table A5 are in dollars, it is impossible to reconcile the estimated price coefficients ranging from -0.5 to -4.7 with elasticities reported in table II of -1.1 to -5.2 (depending on class) assuming price is in dollars. Goldberg (1996) use vehicle purchase price as a proxy for annualized cost and fuel cost per mile, and reports a price coefficient of -2.991 and a fuel cost coefficient of -0.425. Fuel cost is measured in cents per mile while purchase price is presumably in dollars. The ratio of the fuel cost to purchase price coefficients is $0.14 per 1-cent-per-mile.

Applying the standard estimate of discounted lifetime miles implies a present value of 1-cent-per-mile of $1,126. Thus, it does not appear likely that purchase price is in simple dollars per vehicle. The reported elasticities can only be reconciled with the reported parameter estimates by assuming that vehicle price was in units of 10,000 dollars for estimation purposes. This leaves the question of what units fuel cost is in, dollars, cents or some other units.

Goldberg's (1998) analysis is specifically focused on the short-run effects of the CAFE standards, which limited manufacturers' strategies to pricing and domestic/import content decisions. Changes to vehicle design and technology content were excluded. She estimated a nested multinomial logit model of vehicle choice among nine car classes. Within each class, consumers had a choice between a foreign or domestic car. The vehicle attributes included were price, horsepower/weight, size, and fuel cost per mile. These were often interacted with household characteristics such as income, household size, education level, etc. The principle data source was the Consumer Expenditures Survey 1985 to 1989. Although Goldberg does not report the empirical results of the estimation of her consumer choice model in her 1998 paper, she does make specific observations about consumer valuation of fuel economy.

> "A question of particular interest for environmental regulation is whether consumers appear to be "myopic," in the sense that they respond more to current changes in vehicle prices, than to changes in fuel costs that are felt over several periods.
>
> "Assuming a discount rate of 5%, and an average vehicle holding period of 7 years, produces vehicle price, and fuel costs semi-elasticity estimates that are very similar in magnitude. Even though these calculations are sensitive to assumptions about vehicle holding periods and discount rates, the numbers used above seem realistic enough to safely say that we do not have any reason to believe that consumers are myopic." (Goldberg, 1998, p. 21)

On the other hand, using our standard assumption of a 14 year lifetime, 112,600 discounted miles, together with a 1987 fuel price of $0.96 and an average MPG of 18, produces a discounted present value of $6,000. Goldberg reports a price elasticity of vehicle choice of -3.01 and a fuel cost elasticity of vehicle choice of -0.5, implying that purchase price has six times the leverage of fuel cost, in terms of a percent change. She also gives the average price of a new car as $12,000. If a present value dollar of fuel cost were equal to a dollar of purchase price, the elasticity of fuel cost (given our standard assumptions) should be half the purchase price elasticity. Since it is one-sixth as large, the implication is that consumers undervalue fuel savings by 1:3.

3.1.3 Studies from the EU

Cambridge Econometrics (2008) carried out an econometric analysis of demand for cars and their attributes for the Department for Transport, UK. The researchers estimated a mixed logit model of vehicle choice using survey data on households in the UK who had purchased a new or less than 12 month old car during the years 2004 and 2007. Households identified the manufacturer, model and engine size of the vehicles they purchased. A separate data base on vehicle attributes was mapped to the survey data to add information on vehicle attributes such as transmission, purchase price and fuel consumption. It also provided an estimate of fuel costs for

12,000 kms of travel. Interestingly, both fuel costs in pounds per 100 km, and fuel consumption in liters/100km were included as vehicle attributes in the model estimation. Fuel consumption was not statistically significant but fuel costs were. This may indicate a greater sensitivity to fuel price than fuel economy but the authors did not explore this question.

The report estimates the value of a reduction in fuel costs by the ratio of the mean value equation coefficients of vehicle price (-0.380) and fuel cost per 100km (-0.745), obtaining a ratio of 0.380/0.745 = 0.510. This is interpreted as a willingness to pay £510 per £1/100km reduction in operating costs. This calculation implies that vehicle price is measured in thousands of pounds. But this is not stated in the report, indeed, it is stated in several places that purchase price is measured in units of pounds. Moreover, the ratio used is the marginal utility of a pound in purchase price to the marginal utility of a pound per 100km in fuel costs. This ratio (actually the negative of this ratio) is the marginal change in fuel costs that equates to a £1 change in purchase price, rather than the change in purchase price that equates to a £1/100km change in fuel costs. The latter value should be calculated as follows.

$$-\frac{\partial P}{\partial F} = -\frac{\frac{\partial U}{\partial F}}{\frac{\partial U}{\partial P}} = -\frac{-0.745}{-0.380} = -1.96 \qquad (9)$$

Thus, a decrease of £1/100km in fuel costs equates to a £1.96 increase in purchase price. That is, consumers would be indifferent between no change in vehicle attributes and a decrease of £1/100km in fuel costs coupled with a £1.96 increase in purchase price. Put another way, consumers would be willing to pay up to £1.96 in increased purchase price for a £1/100km reduction in fuel costs. If price is indeed measured in thousands of pounds, the willingness to pay for a £1/100km reduction in fuel costs would be £1,960.[7] An average annual vehicle use of 15,000 km is used in the study, implying a discounted lifetime kilometers traveled on the order of 100,000 or more. This value appears to imply that consumers in the UK somewhat overvalue fuel cost savings, since 100,000 km × £1/100 km = £1,000.

Eftec (2008) estimated an aggregate discrete choice model for purchases of automobiles by households in the UK. Their data consisted of counts of the numbers of new vehicle registrations of 2,190 different vehicle types, by households by region of the UK, from 2001 to 2006, a total of 847,689 records. Data on vehicle attributes were matched to the new registration records, as were demographic and income data for the 11 Government Office Regions of Great Britain in which the vehicles were registered.

The report states that "…we scale all cost related variables by the market average income…" and in table 5.1 fuel cost per 100km is listed as one of the variables scaled by average income.

[7] Although it does not appear to be clearly stated in the text, vehicle price was apparently in units of £1,000s rather than pounds. Also, in the text of the report (p. 55) the willingness to pay for fuel economy is calculated by dividing the price coefficient by the coefficient of fuel costs, the inverse of the correct procedure. An e-mail request for clarification has been sent to the authors but no response has been received at time of writing.

However, this assumption leads to the inference that households in the UK place very little value on fuel costs, as will be shown. On the other hand, the mathematical derivation of the model presented in chapter 3 states that fuel costs are treated differently from the fixed costs of vehicle ownership and are included among the other physical attributes of the vehicle. This implies but does not clearly state that fuel costs may not have been scaled by average income.

If one assumes that fuel costs have been scaled by average income, the ratio of the coefficients of Fuel Cost/Purchase Price -((du/dFC)/(du/dPP)) yields an implied value of -£0.385 per increase of £1 per 100km in fuel cost. Since, over the life of a car, there are likely to be on the order of 100,000 kms of travel, one would expect the present value of a change in fuel cost for a £1/100km change in fuel costs to be on the order of £1,000, more than three orders of magnitude larger. Average household incomes by region range from £26,921 to £40,540 in 2005, with the median region at £30,189. Recalculating the value of a £1/100km change in fuel costs while scaling just the purchase price coefficient by median income implies a value of –((-0.3850)/(-1.0165))30189=- £11,434 per £1/100km. This estimate, on the other hand seems roughly one order of magnitude too high.[8] Neither result seems satisfactory.
The authors of the Eftec report are well aware of the statistical difficulties in estimating a vehicle choice model as detailed as theirs.

> "The estimation data set consisted of some 70,850 observations, where each observation relates the market share of a particular type of vehicle in a particular GOR in a particular year to the physical and cost attributes of that vehicle. This represents one of the most comprehensive data sets of its kinds ever compiled. All the same, it remains unlikely that the variables available to describe the physical attributes are sufficient to capture the myriad details that differentiate one vehicle from another.
>
> "The existence of unobserved vehicle attributes is a real problem for the robust estimation of the parameters of the utility function. Indeed, if unobserved attributes are not controlled for in the estimation procedure, the estimated parameters will in all likelihood be biased." (Eftec, 2008, p.xiii- xiv)

The authors attempt to control for the problem of unobserved attributes by including fixed effects for every make, model, body type, and fuel combination. However, even this may not have been enough.

Vance and Mehlin (2009) estimated a nested multinomial logit model of new car registrations in Germany using the method of Berry, Levinsohn and Pakes (1995). The data were obtained from R.L. Polk Europe and provide total sales by over 6,000 makes, models, configurations and body styles each year, aggregated to 681 individual models spanning the years from 1995-2005 (5,007 observations). Two alternative nesting structures were estimated: (1) vehicles grouped into eight classes by size, body style and price, and (2) a further subdivision within each class into foreign and domestic brands.

[8] A request for clarification of this point was sent to the authors via e-mail. Receipt of the e-mail was acknowledged and a substantive response is expected soon but was not available in time for inclusion in this draft.

Fuel economy was represented by the product of fuel price (€/liter) multiplied by the New European Drive Cycle fuel consumption rate in liter per 100 km, or €/100km. Vehicle purchase price was represented by the retail price divided by the national disposable income level per capita. Other variables included in the model were:

1. The annual circulation tax (e.g., € 5.11 to € 6.75 per 0.1 liter for gasoline passenger cars)
2. Engine power in kW
3. Vehicle size, measured by length times width
4. Curb weight
5. Dummy variables for each year

The estimated coefficients of fuel costs per 100 km and car price/income were similar in the two nested logit models. The model nesting by vehicle class only produced a fuel cost coefficient of -0.197 and a vehicle price coefficient of -0.272, while the model nesting by vehicle class produced corresponding estimates of -0.186 and -0.255. The ratio of the two, which determines the willingness to pay for fuel economy, is nearly identical. Calculation of the willingness to pay for fuel economy requires the average income per capita for the sample period (€ 16,017, kindly provided by the corresponding author) and data on vehicle use and expected lifetime. Annual usage is assumed to be 16,000 kms per year for a new vehicle declining at 4% per year over a 15 year vehicle life. This yields 117,520 discounted lifetime kilometers or 1,175 segments of 100 kms each. The willingness to pay for a € 1 reduction in fuel cost per 100 kms is given by the following equation, in which E is fuel cost in Euros per 100 km, P is vehicle retail price in Euros and Y is per capita income in Euros.

$$\left(\frac{\frac{\partial U}{\partial E}}{\frac{\partial U}{\partial P}/Y}\right)=\frac{\text{Euros}}{\text{1 Euro/100km}}=\frac{-0.197}{-0.272/16017}=11601 \tag{10}$$

This implies that a typical German new car buyer would be willing to pay € 11,601 to reduce the fuel costs of a new vehicle by € 1/100 km. How reasonable this is requires knowing how many hundreds of kilometers a new vehicle is likely to travel over its lifetime. Multiplying the hundreds of kilometers by € 1 and discounting to present value gives the present value of the future savings in fuel produced by a € 1 / 100 km reduction in fuel costs. Let K_o be the kilometers traveled by a new vehicle and q be the annual rate of decline in kilometers traveled. Let L be the lifetime of a vehicle in years and r be the consumer's annual discount rate. If a vehicle in Germany travels an average of 16,000 kilometers in its first year, declining at 4% per year over a 15 year life expectancy, and assuming a discount rate of 7% per year, a €1 change in fuel costs per 100 km should be worth approximately € 1,175 in present value.

$$PV=\frac{€\,1}{100}\int_0^L K_o e^{-qt}\,e^{-rt}dt=€\frac{16000}{100}\int_o^{15} e^{-(.04+.07)t}\,dt=€\,1175 \tag{11}$$

The willingness to pay per present value Euro in fuel savings calculated from Vance and Mehlin's (2009) model in this way is almost ten Euros, and varies little between the vehicle class (€ 9.87) and the class/origin (€ 9.94) nesting strategies. It is not obvious why rational consumers would be willing to pay an order of magnitude more for an improvement in fuel economy than it is worth in present value.

3.2 HEDONIC PRICE MODELS

Fan and Rubin (2009) estimated a hedonic demand regression for the state of Maine in 2007, using a two-stage method that allowed them to estimate a demand function for fuel economy. Their first stage regression is of greatest interest here because it can be compared with the studies by Espey and Nair (2005) and McManus (2007) discussed below. Fan and Rubin's data base contained information on 523 passenger cars and 2,100 light trucks, with vehicle attributes obtained from Ward's Automotive Group. A Box-Cox test for functional form indicated that the log-log form should be used for estimation. Their first-stage model regressed log of manufacturer's suggested retail price (MSRP) against the logs of MPG, vehicle weight, and horsepower to weight ratio, and dummy variables representing vehicle class, transmission type and manufacturer. A second first stage regression was run adding interactions between the vehicle class dummy variables and the vehicle attributes, in order to explore heterogeneity in consumer preferences across classes.

The results for passenger cars and light trucks indicated a willingness to pay for a 1 MPG increase in fuel economy of $208 for cars and $233 for light trucks. The authors note that these values are small in comparison to their estimated undiscounted lifetime fuel savings of $823 for passenger cars and $1,461 for light trucks. They state that the implied discount rates are 48% for cars and 13% for light trucks, but these estimates are not consistent with the numbers for lifetime savings. However, recalculating the implied discount rates using national data on vehicle usage and survival rates (U.S. DOT/NHTSA, 2006) and national average model year 2007 MPG numbers (U.S. EPA, 2009), and assuming a national average gasoline price of $2.85 per gallon (2007 $), this author obtains implied discount rates of 37% for cars and 77% for light trucks.

The estimates of willingness to pay for fuel economy by vehicle class, shown in Figure 4, raise additional issues. They show negative willingness to pay for some significant vehicle classes and substantial variability across classes that is not easy to explain. The authors' suggested interpretation is consistent with omitted variables bias, that is, MPG is aliasing other vehicle attributes which are not included in the regression equation but with which MPG is correlated.

> "Although luxury and large car consumers may not be intentionally unwilling to pay for higher fuel economy, luxury car consumers' preferences for luxury features, and large car buyers' primary needs for large sizes might compromise their value on fuel economy." (Fan and Rubin, 2009, p. 9)

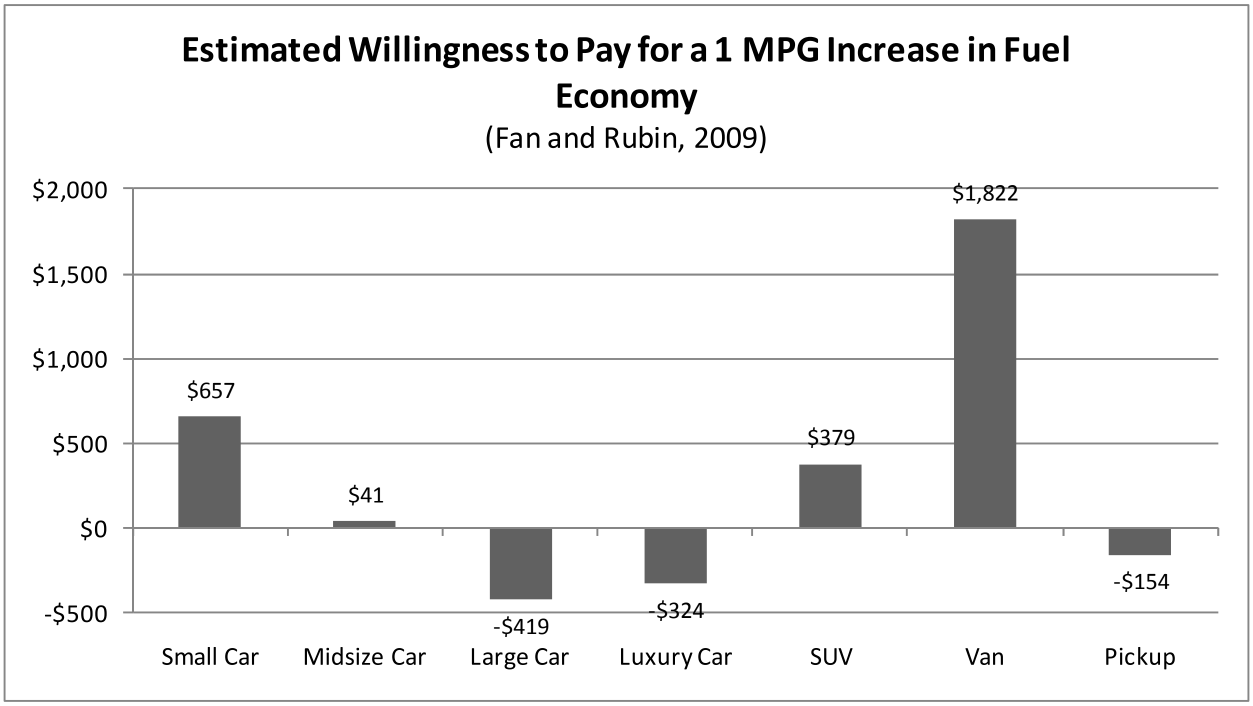

Figure 4. Estimated Willingness to Pay for a 1 MPG Increase in Fuel Economy by Vehicle Class. Source: Fan and Rubin (2009).

Espey and Nair (2005) used a hedonic model applied to 2001 automobiles to estimate the value of fuel economy to consumers and concluded that consumers fully value lifetime vehicle fuel savings, and perhaps more. The authors note the relative scarcity of studies (at that time) of the value of fuel economy despite the importance of the issue.

> "Surprisingly few economic studies have attempted to determine consumers' willingness to pay for improvements in automobile fuel economy." (Espey and Nair, p. 317)

The authors cite the method of Rosen (1974) as their methodological approach for regressing vehicle price on attributes including fuel economy. However, Rosen's method explicitly recognizes the simultaneity of the supply and demand for vehicle attributes and, therefore their price whereas the authors use a single-stage estimation method based on least square corrected for heteroskedasticity. A critical issue is whether the analysis is identifying the supply or demand curve for fuel economy. The authors point out that their method depends on the market achieving equilibrium.

> "Given an equilibrium market, this value reflects both the consumer's marginal willingness to pay for an additional unit of that attribute and the producer's marginal cost of providing another unit of that attribute in that vehicle." (Espey and Nair, 2005, p. 318)

Given the existence of fuel economy standards that were a binding constraint on at least some manufacturers during this period, it is not clear whether the analysis has identified the consumers' willingness to pay or the manufacturer's marginal cost. The full Rosen method, as implemented by Fan and Rubin, does assure identification of the consumer's demand curve.

The data used in the study represented 130, 2001 automobiles whose attributes were obtained from standard sources, such as *Consumer Reports* and Ward's Automotive Report web sites. In addition to fuel economy, seven vehicle attributes were included in the regression analysis: size, power, performance, safety, comfort, reliability and whether or not the vehicle is classified as a luxury vehicle. In the models estimated, these factors were represented by curb weight, 0-60 mph acceleration, turning circle radius, braking distance in feet, the sum of NHTSA's front and side crash test ratings, and a 1-5 comfort rating, a 1-5 reliability rating and a luxury designation (presumably from *Consumer Reports*). Fuel economy was measured as its inverse, gallons per mile, and city, highway and the combined average fuel economy ratings were tested separately. In addition, four categories of the gas guzzler tax were also included.[9] Four models were estimated using least squares corrected for heteroscedasticity, each using a different fuel economy variable: (1) city gpm, (2) highway gpm, (3) both city and highway gpm, and (4) combined gpm. It is assumed that adjusted fuel economy numbers were used. The estimated value of fuel economy ranged from $282/MPG for the highway MPG variable, to $613/MPG for the combined MPG variable. The authors compute undiscounted values of fuel saving, assuming vehicles travel 145,000 miles. This is lower than the NHTSA's estimate of undiscounted lifetime miles (168,853) but higher than discounted lifetime miles (112,600). At $1.50 per gallon, the undiscounted fuel savings for a vehicle driving 145,000 miles at the average automobile MPG of 20.4 would be $561, while at $2 per gallon the undiscounted value would be $747/MPG. Thus, Espey and Nair (Table 5) conclude,

> "…model 4 estimates a higher value of an incremental change in fuel economy than the actual fuel cost savings at a price of $1.50 per gallon.
> "However, for higher fuel prices, the estimate from model 4 using average fuel economy suggests only moderate discounting by consumers, at a rate of about 1% for fuel prices of $1.75 per gallon and 4% for fuel prices of $2.00 per gallon."
> (Espey and Nair, pp. 321-322)

[9] Espey and Nair include the gas guzzler tax as if it were paid by consumers. In fact, the gas guzzler tax is paid by manufacturers. However, the tax is required to be shown on the vehicle's window sticker.

Table 5. Actual Versus Estimated Value of Fuel Economy

	1 MPG increase in:		
	City MPG	Highway MPG	Average MPG
Model 1	$531		
Model 2		$282	
Model 3	$440	$242	
Model 4			$613
Actual undiscounted fuel savings assuming:			
145,000 miles, $.150/gal	$514	$110	$561
145,000 miles, $1.75/gal	$600	$128	$654
145,000 miles, $2.00/gal	$686	$146	$747

Source: Espey and Nair (2005, Table 4)

McManus (2007) also estimated a hedonic demand model including the price of gasoline divided by fuel economy. His dependent variable was transaction prices for 445 vehicles during the period 2002. Other explanatory variables were horsepower per ton of vehicle weight, vehicle weight, real disposable income per capita and dummy variables for the brand of each vehicle. The estimated coefficient of fuel price divided by MPG was -768. According to the variable definitions, this should mean that an increase of 1 in fuel cost per mile would reduce the price of a new vehicle by $768. Although McManus doesn't state so in his paper, it appears that the measure of fuel cost is cents, rather than dollars per gallon. Translating to dollars per mile, the coefficient would be 76,800. Since this coefficient translates dollars per mile into present value dollars, its units are discounted lifetime miles. Using the standard assumptions in the appendix to this paper, the discounted lifetime miles of a typical U.S. light-duty vehicle are 85,161, very close to McManus' coefficient estimate.[10] Like the results of Espey and Nair, McManus' results imply that consumers would, approximately, somewhat under-value the lifetime fuel savings due to fuel economy improvements, by about 10%. The two studies use a similar methodology. As noted below in the discussion of Espey and Nair's work, no attempt is made to correct for the potential endogeneity of vehicle prices and vehicle attributes, thus, there is a question as to whether the supply or demand curve is being estimated. Also, by using fuel cost per mile as the explanatory variable, the constraint that consumers respond equally and in opposite directions to fuel price and fuel economy is enforced.

Fifer and Bunn (2009) estimated willingness to pay for reduced fuel consumption per mile by means of hedonic regression analysis and compared that willingness to pay with calculated present values of fuel consumption for passenger cars, SUVs, vans and pickup trucks. A key feature of their analysis was accounting for the variation in annual miles traveled across households and the implications for willingness to pay for fuel economy. Their data on 2,054 makes and models of new cars and light trucks for the period 1996 to 2005 included vehicle price, fuel consumption (gallons per mile), weight, horsepower, engine displacement and presence of airbags. Different coefficients for the fuel consumption variable were estimated for

[10] These assumption are, 15,600 miles per year when new declining at 4.5% per year, an expected rate of return on an investment in fuel economy of 12% and an expected 14 year lifetime (NRC, 2002, p. table 4-1).

four broad market segments: (1) passenger cars, (2) SUVs, (3) vans, and (4) pickup trucks. Dummy variables were also included for model year, manufacturer and "detail" market segment. Detail market segments are subsets of the four segments for which different fuel consumption coefficients were estimated (e.g., for passenger cars: subcompact car, compact car, midsize car, large car, luxury car).

The authors note that 1996-2005 was a period over which there was very little variation in the average fuel economy of new vehicles. In their sample, the average fuel economy of a new vehicle was 21 MPG and was relatively constant over all ten years. Not only was there little variation in new vehicle fuel economy (see Figure 1), but there was no variation in the fuel economy standards until 2005, when the light truck standards increased from 20.7 to 21.0 MPG; the passenger cars standards remained at 27.5 throughout the period. This is potentially significant because if the fuel economy standards were a binding constraint on some or all manufacturers for some or all of this period, hedonic regression estimates of consumers' willingness to pay for fuel economy improvements could reflect the shadow price of the standards rather than true willingness to pay.

To account for the effect of heterogeneity in vehicle use on the value of improved fuel economy, the authors used data from the 2001 National Household Travel Survey (NHTS) to estimate annual mileage for each of the four vehicle types. Median annual usage varied across the four vehicle types as follows: cars, 9,185; pickup trucks, 9,500; vans, 11,400; SUVs, 11,800. The NHTS does not measure the actual use of each vehicle over a full year. Instead, it develops a "best guess" estimate based on a combination of odometer readings and survey responses. Vehicles up to five years old were included in the calculation of the expected present value of fuel savings.

Fifer and Bunn (2009) assumed consumers would perceive fuel prices to be a random walk, and thus take the current price of fuel to be the best predictor of fuel price over the life of a new vehicle. Indeed, fuel prices varied little over the sample period. Fuel prices increased from a median (over states) of $1.23 in 1997 to $1.40 in 2001. The expected present value of fuel savings was calculated as the current price of fuel time the sum over the vehicle's expected lifetime (assumed to be 14 years for all vehicle types) of the product of miles traveled, multiplied by the rate of fuel consumption per mile, times a discounting factor for the year in question. Discount rates of 3% and 7% were used. Using this method and the 3% discount rate, they calculated the expected present value of a 0.001 gallon per mile reduction in the rate of fuel consumption to be $167.42 for cars, $193.97 for pickups, $194.67 for vans and $197.78 for SUVs.

The hedonic regression results are shown in Table 6. The regression is linear in levels of the variables, and all variables are statistically significant except the airbags dummy, and the coefficient of gallons per mile for cars in Regression 1. Regression 2 combines cars and SUVs to estimate a single coefficient for both variables. The willingness to pay for a reduction in fuel consumption of 0.001 gallons per mile equals the coefficient estimate in Table 6 divided by 1,000 (for example, for cars & SUVs in Regression 2, that would be 87,349.1/1,000 = $87.35). The most striking feature of the regressions is the very large differences in willingness to pay between purchasers of cars or SUVs and vans or pickup trucks. According to Regression 2, on average, pickup truck buyers will pay more than six times as much to reduce their vehicle's rate of fuel consumption (gallons per mile) as car or SUV buyers, and purchasers of new vans will pay more than five times as much. These differences cannot be accounted for by the somewhat higher rates of usage for pickups and vans, about 20%, on average.

Table 6. Fifer and Bunn's (2009) Hedonic Regression Results

	Regression 1			Regression 2		
Variable	Coefficient	Std. Err.	t-stat.	Coefficient	Std. Err.	t-stat
cars*GPM	-73022.64	43490.2	-1.68			
vans*GPM	-471770.3	103601.6	-4.55	-468153	103508.6	-4.52
SUVs*GPM	-126319.9	60676.48	-2.08			
pickups*GPM	-553761.6	95299.28	-5.81	-549569	95167.13	-5.77
(cars+SUVs)*GPM				-87349.1	40142.99	-2.18
Hp	28.78605	6.204614	4.64	29.90907	6.064106	4.93
Wt	7.693808	0.521927	14.74	7.609789	0.5125924	14.85
Displacement	3986.338	408.7145	9.75	3954.065	406.9469	9.72
Airbags	130.4298	447.148	0.29	138.2672	447.0245	0.31
Detail Segment Dummies						
Year Dummies						
Manufacturer Dummies						
_cons	-9576.885	3910.963	2.45	-11244.6	3391.639	-3.32
Number of obs	2048			2048		
F(54, 1993)	216.4			220.5		
Prob > F	0			0		
R-squared	0.8543			0.8542		
Adj R-squared	0.8503			0.8504		
Root MSE	5697.1			5696.8		

On the other hand, when the authors aggregate all vehicle types, they obtain results very similar to those of Espey and Nair (2005) and McManus (2007), namely that consumers' willingness to pay for fuel economy improvement, on average, is approximately equal to the present value of fuel saved.

> "Combining observations from all four vehicle segment (sic), there is a net underpayment of $4.93 per capita for the low-end discount rate and a net overpayment of $37.17 per capita for the high-end rate. While this combination of all vehicle segments suggests a small to negligible net overpayment, car and SUV buyers generally reap large benefits while van and pickup buyers incur large losses from their investments in fuel economy. Aggregating the results by summing across all vehicle segments misses the more nuanced result that "rationality" depends greatly on the type of vehicle purchased and driven by the consumer." (Fifer and Bunn, 2009, p. 20)

The authors, however, are not able to come up with an explanation that satisfies them as to why apparent rationality should vary by vehicle type.

> "This raises an interesting question that is beyond the scope of our analysis: unless it is technologically infeasible, why don't van and pickup producers introduce more fuel efficient vehicles to capture the profits suggested by these hedonic prices?" (Fifer and Bunn, 2009, p. 21)

In fact, analyses of the technological potential and cost of improving fuel economy have found that it is no more, and perhaps less costly to improve the fuel economy of vans and pickup trucks than of passenger cars and SUVs (e.g., NRC, 2002).

The data used by Fifer and Bunn (2009) presents the usual challenges for statistical inference of the value of automobile attributes. The three included continuous variables (horsepower, weight and engine displacement) are strongly correlated with fuel consumption and with each other. For example, Knittel (2009) found that weight and horsepower, together with dummy variables representing diesel engines and manual transmissions, achieved an R^2 of 0.848 in a double log regression on fuel consumption. In addition, manufacturers generally package other features with engine options (sunroofs, alloy wheels, premium floor mats or upholstery, special paint, etc.). The extent of packaging can vary considerably. For example, the 2010 Camry SE's 6-cylinder package adds $5,395 to the price of the vehicle while the Chevrolet Malibu's 6-cylinder option adds only $1,795. The two 4-cylinder and the two 6-cylinder engines are almost identical in size and power. Presumably, there is more in the Camry's 6-cylinder package. Such differences will not be captured by make and model dummy variables, let alone vehicle class dummies. In addition, there is the question of the impacts of fuel economy standards. Fifer and Bunn do not attempt to represent the effects of the standards in their model. This leaves open the possibility that if the standards were a binding constraint on manufacturers, what Fifer and Bunn have estimated is the supply function for fuel economy rather than consumers' willingness to pay. If the standards were binding on some manufacturers and not other, or if they were binding in some years and not other, the identification of the estimates as consumers' willingness to pay becomes even more complicated.

Arguea, Hsiao and Taylor (1994) estimated the marginal value of fuel economy using hedonic regression analysis and eighteen years of data from 1969 to 1986. Fuel economy was represented by *Consumer Reports* magazine's open-road miles per gallon estimates. Ordinary least squares were used to estimate a linear hedonic price function in current dollars. The resulting year-by-year hedonic price coefficients for fuel economy represent the value of an increase of 1 MPG, and are illustrated by the gray bars in Figure 4. The present value of lifetime fuel savings resulting from a 1 MPG increase in the highway fuel economy of an average passenger car (U.S. EPA, 2009, table 1, adjusted highway MPG) was calculated using the standard vehicle usage and discounting assumptions (see appendix), and the current dollar price of gasoline in each year (U.S. DOE/EIA, 2009, table 5.24). The ratio of the hedonic price estimate to the estimated present value of fuel savings, expressed as a percent, is shown by the larger unshaded bars in Figure 5. In general, the apparent willingness to pay for fuel economy is in the vicinity of 5% to 10% of the calculated present value of fuel savings, except for the final year, 1986, in which the estimated willingness to pay is 46% of lifetime fuel savings.

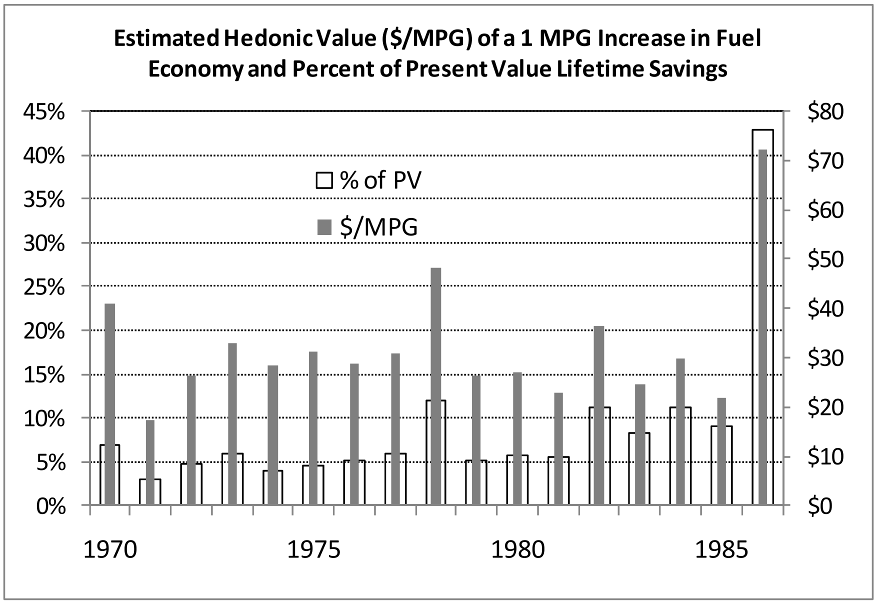

Figure 5. Annual Estimates of the Hedonic Value of a 1 MPG Increase in Fuel Economy and the Percent of Estimated Lifetime Fuel Savings Each Represents (Arguea, Hsiao and Taylor, 1994).

Espey and Nair (2005) use data from a single year, 2001, to estimate their model. As Arguea, Hsiao and Taylor (1994) point out, this poses a potential problem because the estimated hedonic prices of attributes represent an *assumed* equilibrium of supply and demand.

> "From a single shadow price representing equilibrium of market demand and supply, it is not possible to separately identify the structural demand and supply functions for these characteristics." (Arguea, Hsiao and Tayler, 1009, pp. 6-7)

The potential problem arises if for some reason supply and demand are not in equilibrium. There is a strong possibility that what McManus, Espey and Nair, and Fifer and Bunn have estimated is the supply function for fuel economy and other vehicle attributes or a mixture of supply and demand. Fuel economy standards for automobiles were in effect for the years covered by both analyses. What studies finding cost-effective willingness to pay for fuel economy may be showing is that the fuel economy standards were binding and that they required manufacturers to provide levels of fuel economy that were approximately cost-effective based on expected lifetime fuel savings. In the event the fuel economy standards were not binding, then market forces may have led manufacturers to provide cost-effective levels of fuel economy. In the latter case, one could reasonably assert that the marginal cost of fuel economy should equal the marginal willingness to pay, and thus should be a relevant estimator of it. If the former, then marginal cost would equal or exceed marginal willingness to pay. Without a clear identification of the supply and demand curves, the question cannot be resolved definitively. Determining when fuel economy standards were binding and on which manufacturers might be useful for identifying the consumers' demand function.

Fan and Rubin's (2009) results, however, were inconsistent. They found that MPG coefficients for luxury cars, large cars and pickup trucks all indicated a negative value for higher fuel economy. These results should probably be interpreted as coefficient bias as a result of fuel economy aliasing unobserved attributes. Other interpretations seem implausible: (1) purchasers of these vehicles are averse to saving money and prefer to make extra trips to the refueling station, and (2) for purchasers of these vehicles, there is a snob effect associated with lower fuel economy, everything else equal. This last interpretation seems to be favored by Fan and Rubin but it is inconsistent with the assumption that other factors are held constant. It is difficult to believe that even if consumers could have all the other attributes associated with luxury and size and improved fuel economy they were willing to pay for, they would still prefer lower fuel economy. This implies a negative utility for saving money, which seems implausible for large market segments.

3.3 OTHER METHODS

Kilian and Sims (2006) analyzed the effect of changes in fuel cost per mile on the prices of individual makes and models of used cars in the United States for the years 1978-1984. Their partial equilibrium model of automobile pricing considers automobiles to be assets producing a flow of services to households over the lifetime of the vehicle. The supply of used vehicle services is assumed to be fixed, which is not entirely correct since vehicle lifetimes can be extended by investment in maintenance and repair. The annual rental rate (R_{ijt} = value of flow of services for vehicle i of age j in year t) is a function of services (U) derived from observable and unobservable attributes (Z) and operating costs, represented by fuel cost. Fuel costs are equal to the price of gasoline (p_t) times annual miles of travel by vehicle i (m_{it}) divided by the fuel economy of vehicle I (MPG_i).

$$R_{ijt} = U(Z_i, m_{it}) - \frac{p_t m_{it}}{MPG_i} \tag{12}$$

The current price of a used vehicle (P) is assumed to be the present, discounted value of future, expected service flows, or rental flows over the vehicle's lifetime (L).

$$P_{ijt} = \sum_{j=0}^{L-j} (1-r)^j \, E_t\left[R_{ijt}^*\right] \tag{13}$$

From the equation for used car prices it is clear that a decrease in the present value of expected fuel costs of a certain amount should increase the price of a used car by the same amount. If the other attributes of a vehicle are assumed to remain constant, then the effect of an increase in the price of gasoline on the price of a used car is just the discounted present value of the increase in expected fuel costs.

$$X_{ijt} = \Delta P_{ijt} = \sum_{j=0}^{L-j} (1-r)^j \, E_t \left[\frac{-\Delta p_t m_{it}}{MPG_i} \right] \tag{14}$$

In the form of the model used for estimation, the change in used car prices and all other variables are expressed relative to the initial used car price. In the equation below, δ_t represents fixed time effects and ω_{ijt} represents the flow of vehicles services (other than fuel cost) in time period t.

$$\frac{P_{ij+1t+1} - P_{ijt}}{P_{ijt}} = -(\delta_t + \omega_{ijt}) + \gamma \frac{X_{ijt}}{P_{ijt}} + e_{t+1} \tag{15}$$

Kilian and Sims assume that all vehicles have the same lifetime (L = 10 years), the same usage rates (m_{it} = m = 10,000 miles per year) and that all consumers have the same discount rate (5% per year). In general, these assumptions appear to be low relative to other data sources (see appendix) which would tend to underestimate the present value of a change in fuel prices and overestimate the impact of fuel price changes on used car prices. In addition to these assumptions, the model also requires a way to represent consumers expectations about future fuel prices. The reference assumption is static expectations, an optimal method if gasoline prices are a random walk. However, a variety of other price expectation models were tested, including fitted ARIMA and GARCH models, as well as lagged updating of expectations.

Data on fuel economy for 2,780 light-duty vehicles for the period 1978-1984 were obtained from official EPA/DOE estimates. Used car price data were collected from the National Automobile Dealers' Association *Used Car Price Guides* for the years 1979-1989, since used cars up to five years of age were included in the analysis. Gasoline price data were obtained from the Energy Information Administration's *Monthly Energy Review*.

The coefficient of the present value of the change in gasoline price relative to the lagged used vehicle price (γ) is predicted to be -1 by Kilian and Sims' theory. Results from the baseline model employing static expectations finds a coefficient of -0.1096, indicating that only 11% of the change in present value expected fuel costs translates into a change in used vehicle prices. Interpreted as a willingness to pay for fuel economy, it would imply that in used vehicle transactions, consumers are willing to pay for only 11% of a reduction in fuel costs per mile. The authors provide a sample calculation for the effect of a $0.25 per gallon price change for two vehicles costing $10,000 each, with one getting 15 MPG and the other 25 MPG. Their theory predicts that the 15 MPG "gas guzzler" should experience a reduction in price of $1,000 while the 25 MPG vehicle should lose only $600, for a net advantage of $400 for the more fuel efficient car. The estimated model, however, predicts only a $50 relative price change.

Including different formulations of fixed effects did not change the resulting estimates in any important way. Excluding all foreign autos, light trucks and diesel autos, however, produced a coefficient estimate of -0.288, still far from -1.0. Fitting an ARIMA model to prices and using it in place of static expectations resulted in uniformly lower impact estimates. The authors then systematically varied their assumptions about vehicle life, usage and discount rates. Only by decreasing annual use to 5,000 miles per year, lowering the expected lifetime to 6 years and assuming discount rates in excess of 10% could coefficient estimates of -1 be obtained.

> "We thus conclude that the baseline model cannot be rationalized for reasonable calibrations of the parameters or assumptions regarding expectations formation. …Either individuals are extremely myopic and do not factor the near future into their decisions or the theory and/or empirical specification is flawed in a more fundamental sense." (Kilian and Sims, 2006, p. 16)

The authors then try several other models of gasoline price expectations, including a twelve month average and a random walk model with a GARCH error term. This produced coefficient estimates as high as -0.25 in one case. Finally, the authors test for asymmetric response to gasoline price increases and decreases. In years in which gasoline prices rose, the coefficient of the cost per mile variable was quite close to -1, -0.887, and did not differ significantly from -1. However, in years in which gasoline prices fell the estimated γ was +0.08 and was statistically significantly different from zero. This result was generally consistent across alternative formulations and estimation methods.

> "In particular, a robust finding is that gasoline price increases have a relatively strong effect on used automobile prices while decreases do not." (Kilian and Sims, 2006, p. 25.)

The results on asymmetry may be relevant to the willingness to pay for increased fuel economy, since an increase in fuel economy decreases fuel cost per mile. In fuel economy terms, the asymmetry results imply that consumers will pay nothing or close to nothing for increased fuel economy but would pay close to expected present value to avoid decreased fuel economy. If this result proved to be valid, it would imply that consumers respond differently to fuel price and fuel economy.

Bhat and Sen (2006) constructed a model of household vehicle holdings and use by vehicle type, using data from a 2000 survey of consumers in the San Francisco Bay area. Their multiple discrete-continuous extreme value (MDCEV) model did not include the price of vehicles but did include their fuel economy via a variable representing fuel cost per mile divided by household income. Because vehicle price did not appear in their model, the value of fuel economy cannot be directly calculated. However, Bhat and Sen did compute the elasticities of vehicle choice by vehicle type with respect to fuel cost per mile by varying fuel cost from $1.40 per gallon to $2.00 per gallon (a 35% increase based on the midpoint formula). These elasticities are quite low compared to typical estimates of the price elasticity of vehicle choice, which are on the order of -2 to -3. Very roughly, the discounted present value of total lifetime fuel costs is on the order of $10,000, while a typical vehicle costs on the order of $20,000. Thus, a given percent change in discounted present value fuel costs (represented by a percent change in fuel cost per mile) should have approximately half the impact on vehicle holdings as the same percent change in own price. Given this, Bhat and Sen's elasticity estimates shown in table 7 suggest a significant under-valuing of fuel economy.

Table 7. Elasticity of Household Vehicle Choice with Respect to Fuel Cost per Mile

	Pass. Car.	SUV	Pickup	Minivan	Van
% change in vehicle holdings	-0.1	-5.9	-2.1	-4.9	-3.4
Fuel cost per mile elasticity	-0.002	-0.169	-0.006	-0.140	-0.097

In an analysis of the short-run effects of fuel prices on vehicle prices, **Langer and Miller (2008)** found that when gasoline prices rise, the prices of inefficient vehicles fall while those of especially efficient vehicles rise. Using 300,000 observations of weekly automobile price data over the period 2003-2006, they measured the extent to which the prices of new light-duty vehicles responded to changes in the price of gasoline. Their dependent variable was a constructed "manufacturer price," comprised of the manufacturers' suggested retail prices minus the average incentives offered by GM, Ford, Chrysler and Toyota in for each week in five geographic regions during 2003-2006.

Their fundamental equation for empirical estimation expresses the price of vehicle j, in time period t, in region r (p_{jtr}) as a function of the price of gasoline ($_{g}p_{tr}$) divided by fuel economy (mpg_j), the sales-weighted average fuel cost per mile of other vehicles made by competitors and the weighted average fuel cost per mile of vehicles made by the same manufacturer. A vehicle is defined as a make/model (e.g., Ford Taurus) in a specific model year. The equation also includes fixed effects for time periods (δ_t) and vehicles (κ_j) as well as third order polynomials of variables representing the length of time vehicle j, vehicles produced by other manufacturers and vehicle produced by the same manufacturer other than j have been on the market, and the weighted average lengths of time other vehicles have been on the market. The functions involving length of time in the market are not shown in equation 5.

$$p_{jtr} = b_1 \frac{p_{gtr}}{mpg_j} + b_2 \sum_{k \nexists M} w_{2jkt} \frac{p_{gtr}}{mpg_j} + b_3 \sum_{l \exists M, l \neq j} w_{1jlt} \frac{p_{gtr}}{mpg_l} + \delta_t + k_j + n_r \tag{16}$$

Equations were estimated with fixed values of the b's for all manufacturers, as well as allowing the b parameters to vary across manufacturers. In the regressions with fixed b values across manufacturers, own fuel cost, b_1, was consistently statistically significant and negative in sign. The effect of the average competitor fuel cost was similar in magnitude, statistically significant but opposite in sign, as might would be expected (Table 8). The effect of same firm fuel costs was generally not statistically significant. Langer and Miller point out two caveats concerning their manufacturer price variable. First, it is not a transaction price, and the negotiations during transactions could push the transaction price in either direction from the manufacturer price. Second, the manufacturer price is based on the average incentive program on offer during the period rather than the actual incentives taken by consumers. If manufacturers allow more combining of incentives during high gasoline prices than during other periods, the impacts of gasoline prices may be underestimated.

It is convenient to measure the magnitude of the effect of fuel costs on vehicle prices relative to the change in expected fuel costs caused by a change in the price of gasoline. Langer and Miller call this the "offset percentage." In calculating expected lifetime fuel costs, they assume static expectations in their base model but explore alternative price expectation models. The median offset percentages in their base model are 18% for cars, 15% for SUVs, and much less for light trucks and vans. For nearly all vehicles, higher gasoline prices reduced manufacturer prices. For especially efficient vehicles, however, higher gasoline prices actually increased the manufacturer prices. For example, among SUVs the Ford Escape Hybrid, Mercury Mariner Hybrid, Toyota Highlander Hybrid and Lexus RX 400 Hybrid were the only SUVs whose prices increased when gasoline prices increased.

Table 8. Manufacturer Prices and Fuel Costs

Variables	Incentive Level		
	Regional+ National (1)	Regional Only (2)	National Only (3)
Fuel cost	-55.40	-56.96	-63.75
	(7.73)	(7.86)	(8.77)
Average competitor fuel cost	50.76	50.16	50.09
	(7.15)	(7.39)	(8.12)
Average same-firm fuel cost	1.15	2.62	1.31
	(2.29)	(1.78)	(2.30)
R^2	0.5260	0.6763	0.5289
# of observations	299,855	299,855	59,971
# of vehicles	681	681	681

Source: Langer and Miller (2008, table 3)

While Langer and Miller's results clearly indicate that manufacturers adjust vehicle prices when fuel prices change, they do not indicate whether consumers are over- or undervaluing the potential fuel savings. This would require an understanding of how consumers form price expectations for the life of a vehicle, an issue that Langer and Miller do not believe could be resolved with the data used in their study. It would also depend on the short-run price elasticities of vehicle demand and supply. If new vehicle supply were perfectly elastic, a change in fuel costs would affect quantities sold but not prices. If supply were perfectly inelastic, price would change by the full present value of the change in expected lifetime fuel costs. This question is also not addressed by Langer and Miller. However, their results suggest that either new vehicle supply is very elastic or consumers undervalue fuel economy.

Busse, Knittel and Zettelmeyer (2009) estimated the effects of changes in gasoline prices on the market shares and prices of new and used automobiles. Using data from a 15-20% sample of actual vehicle transactions at new car dealers from September 1, 1999 to June 30, 2008, they estimated regressions relating gasoline prices and a variety of control variables to market shares and transaction prices, separately for new vehicle purchases and used vehicle purchases. Fuel economy was brought into the analysis by ranking vehicles' fuel economy and estimating separate equations by quartile. They found that both market shares and vehicle prices responded to fuel price changes in ways that were predictable by economic theory.

Busse et al.'s (2009) findings concerning the effect of gasoline prices on new and used car prices are most relevant for this study. The estimated coefficients for gasoline price for new cars by MPG quartile are shown in Table 9. For new cars, a $1 increase in the price of gasoline reduced the price of the average vehicle in the least efficient quartile by $246, and increased the price of a vehicle in the most efficient quartile by $136, for a net effect of $382. Although two of the four coefficients are not statistically significant, they all follow a logical pattern of increasing cost with decreasing fuel economy. According to estimates made by the authors, the difference between the 1st and 4th quartile values is equal to 1.2 years of (undiscounted) fuel savings (based on an average MPG of 27.9 for the 1st quartile and 16.2 MPG for the 4th, and an average annual mileage of 12,000). These results do not necessarily imply that new car buyers undervalue fuel economy, since the change in price also depends on the elasticities of supply and demand and on the formulation of price expectations.

If used cars supply is perfectly inelastic, then the shift in the demand curve caused by higher fuel prices would exactly equal the reduction in market price. If supply is highly price elastic, the observed change in market equilibrium prices would be only a small fraction of the change in lifetime operating costs even if consumers fully valued lifetime fuel costs because the adjustment to a shift in the demand curve would be primarily a quantity adjustment. On the other hand, if the supply of used vehicles is almost perfectly inelastic, then the change in price would be nearly equal to the change in lifetime operating costs. Price expectations matter because if consumers expect continuing increases whenever fuel prices increase, the calculated change in fuel costs based on static expectations would greatly understate consumers' expected change in fuel costs, and overestimate their willingness to pay for fuel economy.

Table 9. Gasoline Price Coefficient Estimates: New Car Price Equation

Variable	Coefficient (std. error)
Gasoline Price * MPG Quartile 1 Dummy	-246 (75)
Gasoline Price * MPG Quartile 2 Dummy	-81 (40)
Gasoline Price * MPG Quartile 3 Dummy	5.2 (30)
Gasoline Price * MPG Quartile 4 Dummy	136 (43)

Source: Busse et al. (2009, p. 19)

The results for used car market shares and prices were essentially the reverse of the new car results: market shares changed little while prices changed a great deal. Table 10 shows the gasoline price coefficients by MPG quartile for the used car price equation. The pattern is the same but the magnitude of price changes is almost an order of magnitude greater. For used cars, the difference between the 1st and 4th quartiles is $2,723, equivalent to nine years of undiscounted fuel savings. Considering that used cars have a shorter expected life than new cars, the results for used cars suggest an overvaluing of fuel costs by used car buyers.

Table 10. Gasoline Price Coefficient Estimates: Used Car Price Equation

Variable	Coefficient (std. error)
Gasoline Price * MPG Quartile 1 Dummy	-1096 (38)
Gasoline Price * MPG Quartile 2 Dummy	-936 (57)
Gasoline Price * MPG Quartile 3 Dummy	76 (71)
Gasoline Price * MPG Quartile 4 Dummy	1627 (56)

Source: Busse et al. (2009, p. 22)

In general, Busse et al. (2009) found that new car market shares changed more than used car market shares in response to fuel price changes, while used car prices changed more than used car prices. The explanation focused on the supply side and market efficiency. The used car market was believed to function most efficiently, on the premise that there are many used car buyers and sellers (individuals), frequent transactions, and that buyers and sellers alike experience the same change in operating costs when gasoline prices rise, which helps to equate the changes in willingness to pay and willingness to accept. The authors argue that the new car market differs primarily in that the new car manufacturers have market power, and therefore choose not to lower prices when the demand curve shifts downward but rather to accept loss of volume, in part due to the potential damage to their brand's reputation. An alternative explanation could be that the supply of new cars is more price elastic than the supply of used cars. In this case, a downward shift in the demand curve caused by an increase in operating costs would produce a smaller change in price in the new car market but a greater change in sales, or market shares.

The authors performed a variety of sensitivity tests as a check on the robustness of their results. In general, these changes did not fundamentally alter the results described above. A question that may not have been satisfactorily answered is whether price expectations play an important role. The authors tested their model with and without a variable that interacted gasoline prices with an indicator of whether prices had been rising, falling or constant over the past three months. Given the historical volatility of gasoline prices, three months may not be enough time for consumers purchasing a long-lived asset like a car to form a strong view about future price trends. Gasoline prices were generally trending upward over the study period, but especially during the final three years. If consumers' price expectations took longer to develop, this could have an effect on the coefficient estimates.

Robustness tests with and without controls for seasonal and fixed effects show the greatest differences in the estimated coefficients (Busse et al., 2009, table 2). For example, with year*region and month-of-year*region dummies included, the coefficient of gasoline price for the fourth MPG quartile is 136; if the year*region dummies are dropped, that coefficient changes to -796. In the used car equation, the same coefficient switches from 1,627 to -4,053 under the same change in dummy variables. However, in both equations the difference between the first and fourth quartile coefficients is about the same (382 versus 386 in the new car equations and 2,723 versus 2,919 in the used car equations). Still, there is a suggestion in these results that the differences in gasoline price coefficients across equations may be aliasing other factors that vary by quartile.

In the regressions for the probability of vehicle purchases within a fuel economy quartile the authors include an extensive set of control variables for demographics, region and timing of purchase, but they do not include explicit measures of other vehicle attributes. (In other regressions, such as for the probability a purchase will be a new car, they do include fixed effects for detailed vehicle types: make, model, model year, trim level, number of doors, body type, displacement, number of cylinders and transmission type). Since a variety of other vehicle attributes are closely correlated with fuel economy (e.g., acceleration performance, size, luxury features) it is not clear that the fuel economy quartile-specific price coefficients are not aliasing the effect of other vehicle attributes. In this regard, it may be significant that the new and used car price coefficients by quartile are estimated in a single equation without quartile-specific intercepts or other quartile specific variables (tables A-3 and A-7). On the other hand, the authors estimate separate equations for market segments, so not only intercepts but all other parameters are specific to the market segment. In these equations, the market segment-specific constants are significant at the 1% level, and the coefficients of many other variables appear to vary significantly across car classes. These results suggest that there may be unobserved attributes that affect car prices that may be correlated with MPG, and therefore may be biasing the estimated gasoline price coefficients in the MPG quartile equations.

The effect of gasoline prices on fuel economy via two "channels," changes in the distribution of new vehicle purchases and in the composition of the on-road stock of vehicles, was investigated by **Li, Timmins and von Haefen (2009)**. In general, they found that fleet fuel economy was relatively insensitive to the price of gasoline.

> "We find that gasoline prices have statistically significant effects on both channels, but that their combined effect results in only modest impacts on fleet fuel economy. The short-run and long-run elasticities of fleet fuel economy with respect to gasoline prices were estimated at 0.022 and 0.204 in 2005." (Li, Timmins and von Haefen, 2009., p. 135)

Using model and vintage-specific data on vehicle registrations and scrappage from 20 major metropolitan areas in the United States, they estimated models of (1) the distribution of vehicle sales, and (2) vehicle survival rates by fuel economy level. They did not attempt to estimate the impacts of fuel prices on manufacturers' decisions about vehicle technology and design.

The dependent variable of their vehicle sales model is the number of new vehicles registered in fuel economy quantile q, in year t, in metropolitan area m. In the new vehicle model, vehicles were classified into 68 fuel economy quantiles. The key explanatory variables were the price of gasoline and gasoline cost per mile (price divided by MPG). Several other metropolitan area attributes were included, both individually and divided by fuel economy, in order to allow heterogeneity in parameter values across metropolitan areas. Dummies were included for quantiles, year, and region. A lagged adjustment formulation was used and tests for serial correlation and heteroscedasticity were conducted.

$$\ln\left(N_{qtm}\right) = b_0 + b_1 \ln\left(N_{qt\text{-}1m}\right) + b_2 \frac{P_{tm}}{MPG_{qtm}} + b_3 P_{tm} + \text{Other Controls} + \varepsilon_{ctm} \tag{17}$$

In models including sufficient control variables, autocorrelation in the error term was not statistically significant. In the preferred models, the coefficient on the lagged dependent variable was quite small (0.068 to 0.074) indicating that adjustment of new vehicle purchases to gasoline prices was almost entirely complete within one year. In the preferred model, an increase in gasoline prices was found to increase the sales of vehicles in the 60th percentile of the MPG distribution above, and decrease sales of vehicles below the 60th percentile.

In the vehicle scrappage model, the survival probability of a vehicle was assumed to be a logistic function of fuel economy, the price of gasoline and other variables controlling for metropolitan area and vehicle attributes. Two data sets were combined using a method of moments estimation technique: one with make/model detail covering the period 1997 to 2000 and the other with only vehicle class detail for the period 2001 to 2005. The preferred models included only vehicles older than 10 years, which were assumed to be more sensitive to changes in fuel prices and less affected by migrations of vehicles into and out of metropolitan areas. In the preferred model, higher gasoline prices increased the survival probabilities of vehicles with greater than 28.7 MPG, and reduced survival rates for vehicles with lower MPG. The average elasticity of vehicle survival with respect to the price of gasoline was low, -0.026 in the preferred model, but elasticities across vehicle types and areas were up to 5 times as large. Nonetheless, relative insensitivity of survival rates to gasoline price suggests that the fuel economy of the on-road vehicle stock will also be relatively insensitive to the price of gasoline.

Simulations using the new vehicle sales and scrappage models confirmed that gasoline price had a very small impact on the fuel economy of the on-road vehicle stock (via its composition). The estimated short-run elasticities of MPG with respect to the price of gasoline were 0.191 for new vehicles, 0.006 for used vehicles and 0.022 for all vehicles. In the long run, the greatest change in fleet MPG will come about via newer more efficient vehicles replacing the used vehicle stock. In the long run, the simulations indicate a price elasticity of 0.204, that is, a 10% increase in the price of gasoline would eventually result in about a 2% increase in fuel economy. These elasticities were calculated for 2005 when the price of gasoline was $2.34 per gallon. The model implies that elasticities will increase with increasing gasoline price. At $4 per gallon, the elasticities increase by about 50% to 0.033 in the short run and 0.330 in the long run. These elasticities include only the effects of fuel price on consumers' choices among existing new vehicles and not manufacturers' decisions about the technological content and design of vehicles. For the existing fleet, only the impact on the composition of the fleet and not its operation (e.g., speed, maintenance, driving style) are included. Still, this paper offers a rare quantification of both the new vehicle sales mix and on-road fleet composition impacts of gasoline price and fuel economy.

The most recent study of the impact of gasoline price changes on vehicle prices also uses the most detailed data. **Sallee, West and Fan (2010)** estimated a model using approximately 8 million wholesale market transactions for used vehicles. Because the wholesale transactions take place at auction houses, the market is likely to be well-informed and efficient. While the data do not represent retail transactions with final purchasers, it seems reasonable to believe that the wholesale market reflects the likely responses of the retail market. The model is similar to other but includes odometer readings for each vehicle, as well as time-period fixed effects for detailed vehicle types (make, model, model year, cylinder count, engine displacement, transmission and trim style). Let P_{ijt} represent the price of the i^{th} vehicle record of type j, in year t, let C_{ijt} represent the estimated discounted present value of its remaining fuel costs, O_{ijt} represent the vehicle's odometer reading at time of sale, δ_{jt} represent a fixed effect for that vehicle type and time period and ε_{ijt} represent random errors.

$$P_{ijt} = \beta C_{ijt} + \sum_{a=1}^{4} \alpha_{aj} O_{ijt}^{a} + \delta_{jt} + \varepsilon_{ijt} \tag{18}$$

In equation (18) the polynomial odometer terms and the time period fixed effects are intended to represent the value of future services from the vehicle, as well as shocks not reflected in gasoline prices, such as economic conditions.

Expected future fuel cost is the central variable in the analysis. For fuel price expectations, the authors assume buyers consider fuel prices to follow a random walk so that the current price becomes the best estimate of future prices. Other formulations were tested, however, with similar results. Consumers were assumed to discount future costs at r = 5% per year, although rates of 10% and 15% were also tested. Fuel economy is assumed to be constant over the life of the vehicle.

$$C_{ijt} = E_t\left[\sum_{s=t}^{R} H\left(O_{ijt}, X_j\right) \frac{1}{(1+r)^{s-t}} \frac{m_{js} p_s}{MPG_j}\right] \tag{19}$$

The function $E_t[]$ denotes expected value, which could vary by time period. The function H() represents the probability of survival, which is a function of the vehicle's odometer reading and whether it is a passenger car or light truck.

The most important determinant of expected present value fuel costs is the expected remaining vehicle mileage; since it identifies the cost effect versus the time period fixed effects. The key assumption is that mileage, rather than age, is assumed to be the relevant measure of the position of a vehicle in its lifecycle. While other studies have determined remaining expected lifetime using a fixed number of years (e.g., 15), Sallee et al. assume vehicles will travel a fixed number of miles but that cumulative lifetime miles vary by vehicle type (cars versus light trucks and make). Clearly, both age and mileage matter in vehicle scrappage decisions, since used vehicle prices depend on both and not only one or the other. Since other studies rely on age, Sallee et al.'s estimation based on mileage provides a different perspective.

Estimating future fuel costs requires knowing how many more miles remain in a vehicle's lifetime and their distribution over time. The approach is to estimate lifetime mileage distributions separately for passenger cars and light trucks, by make. First, parameters describing the relative intensity of use by vehicle class and make were estimated by regressing a predicted odometer reading as a function of age against each vehicle's actual odometer reading (c indexes passenger cars versus light trucks).

$$d_{ca} = \theta_{cm} O_{icm} + \varepsilon_{icm} \tag{20}$$

The predicted odometer readings were obtained from a U.S. Department of Transportation (DOT) report (U.S. DOT/NHTSA, 2006) that provides an equation for mileage by age. A value of $\theta < 1$ indicates that vehicles of that make are used more than expected based on the NHTSA function. Next the NHTSA functions that predict vehicle scrappage and annual mileage as a function of age were transformed to be functions of odometer reading.[11]

Data for the study come from an enormous database of over 90 million used vehicle transactions at wholesale auction houses from 1990 to 2009. Using truncated Vehicle Identification Numbers (VIN) these transactions are matched to EPA fuel economy ratings using make, model, model year, cylinder count, engine displacement, body type, transmission and trim style. The EPA combined, adjusted fuel economy ratings (the estimates reported to the public) were used to estimate fuel economy. Model years prior to 1978 were dropped from the sample since EPA estimates are not generally available for these years. A 10% sample of the records was taken, leaving still about 8 million cases. The price of gasoline was represented by the monthly national retail price series of the Energy Information Administration (Figure 6), deflated using the CPI-U. The undeflated price series shows a generally rising trend with considerable ups and downs after 2001, with a sudden decline in 2009. Gasoline price varies only by month, while the time-period fixed effects vary by month and vehicle type. What identifies the effect of cost, C_{ijt}, from the fixed effects is therefore the variation in odometer readings from vehicle to vehicle, the differences in expected life implied thereby, and differences in fuel economy.

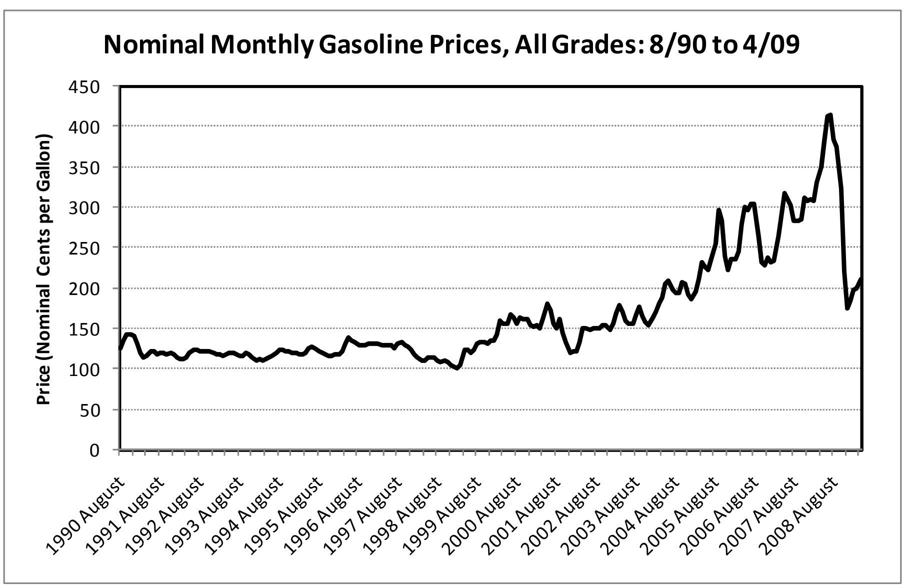

Figure 6. Trend of Nominal Gasoline Prices over the Period of Sallee, West and Fan's (2010) Study.

[11] The report states that, "The base mileage function is then multiplied by the estimated theta for each make to allow for heterogeneity, but we currently impost the same scrappage function on all vehicles." Equation 2, however, implies that the mileage functions should be divided by theta in order to recover the empirical odometer readings.

The estimation results indicate that used vehicle purchasers come very close to fully incorporating future fuel costs into the prices of used cars. The overall estimated beta coefficient for the full sample is -0.788 with a standard error of 0.011, indicating that on average buyers incorporate almost four fifths of the expected costs of future fuel expenditures into the price of the vehicle. The null hypothesis that β = -1 could not be rejected, however. The reference discount rate is 5%. If that is raised to 10%, the β coefficient for all vehicles becomes -1.01. The study also found considerable variation in β values between passenger cars and light trucks and across makes (Table 11). Purchasers of Ford passenger cars, for example, are estimated to incorporate only about 50% of the expected future fuel costs, while purchasers of Toyota cars are estimated to account for more than 90%.

Table 11. Coefficients on the Expected Present Value of Real Remaining Fuel Costs

	Full Sample	
	-0.788 (0.011)	
Makes	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)

There are several areas in which this analysis differs from others. Possibly a key difference is the assumption that the expected remaining vehicle life will be determined by the odometer reading rather than the age of the vehicle. Other studies assume that age will determine remaining vehicle lifetime. Certainly both matter, since vehicles deteriorate with ageing of the materials of which they are made, and their value also declines with technical obsolescence. Another key difference is the use of variation in remaining vehicle use specific to individual vehicles to help identify the valuation of future fuel costs. When the authors restricted their estimation to impose the same odometer coefficients and the same time period effects (both vary by vehicle type in the base model), they find that their beta estimates fall dramatically and are closer to zero than one. A key question for future research is therefore to understand why vehicle type-specific polynomial coefficients and fixed effects have such a pronounced impact on the estimated willingness to pay. The authors also have not yet estimated a model with asymmetric price effects. Kilian and Sims (2006) found a similar valuation of future fuel costs during periods of rising prices (about -0.8) but no value during periods of falling prices. The authors also intend to examine this in future work.

4. SUMMARY AND DISCUSSION

Twenty-seven recent studies have been reviewed for evidence on the value consumers place on fuel economy in their vehicle purchase decisions. The resulting estimates are highly variable. They are summarized in Table 12 in terms of willingness to pay as a fraction of discounted present value of fuel savings or in terms of implied discount rates. There are studies indicating that consumers significantly undervalue fuel economy relative to its expected present value, and there are others indicating that consumers value fuel economy at approximately its expected present value, or much more. This wide disparity of results mirrors the highly variable estimates of implicit consumer discount rates for future fuel savings found by Greene (1983) more than 25 years ago. The persistence of this lack of consensus over a period of decades, despite significant improvements in data and advances in methodology, calls out for an explanation. First, the evidence will be reviewed.

Among the studies using discrete choice modeling to draw inferences from aggregate vehicle sales data, Allcott and Wozny concluded that consumers significantly undervalue future fuel savings at the rate of about $0.25 on the expected present value dollar. Gramlich's (2008) results contradict this finding. His results imply that consumers overvalue fuel savings by a factor of 2 to 3. However, Gramlich's model over-predicted the increase in light-duty vehicle fuel economy from 2007 to 2008 as a result of higher fuel prices by an order of magnitude. Sawhill's (2008) results also imply that consumers overvalue fuel economy but by a factor of 1.3 to 1.4, on average. Berry, Levinsohn and Pakes' (1995) model found the miles per dollar was not a significant factor in consumers' vehicle choices. Taking their estimated coefficient at face value implies that consumers undervalue fuel economy, counting only about $0.01 on the dollar.

Among discrete choice models estimated using survey data, Train and Winston (2007) found that fuel cost per mile was not significant on average, but that the variation across households in preferences for fuel economy was significant. About 60 percent of the population preferred higher fuel economy while 40% preferred lower fuel economy. Like BLP, fuel economy was undervalued, on average, by about two orders of magnitude. Dasgupta, Siddarth and Silva-Risso (2007) found only a slightly high implicit discount rate for fuel economy: 15.2% per annum. Bento et al. (2005) did not directly estimate the value of fuel economy, but the very low elasticities of vehicle choice with respect to fuel costs implied by their model indicate significant undervaluation relative to vehicle price. Feng et al. (2005) found four out of six fuel cost per mile coefficient were significant, and that these consumers valued fuel economy at approximately its expected present value. Estimates made by Brownstone et al. (1996) and Brownstone et al. (2000) using stated preference survey data in general suggest that households overvalue fuel economy by 50% to 67%, but are highly variable across income groups and household demographics, with certain groups preferring less fuel economy. Goldberg's (1995, 1998) estimates show statistical significance for small cars but not large cars. Overall she concludes there is no reason to believe the consumers are myopic. Two studies from the UK appear to show that car buyers there somewhat overvalue fuel economy, although there are questions about the units key variables are in that remain to be resolved.

Table 12. Summary of Consumers' Evaluation of Fuel Economy Improvements Based on 27 Recent Studies

Authors	Model Type	Data / Time	W-T-P as % of Discounted PV	Implied Annual Discount Rate
Alcott & Wozny (2009)	Mixed NMNL	Aggregate U.S., 1999-2008	25%	> 60%
Gramlich (2008)	NMNL	Aggregate U.S., 1971-2007	287% to 823%	
Berry, Levinsohn & Pakes (1995)	NMNL	Aggregate US, 1971-1990	<1% Non-significant	
Sawhill (2008)	Mixed NMNL	Aggregate U.S., 1971-1990	140%, range of -360% to 1,410%	
Train & Winston (2007)	Mixed NMNL	Survey, U.S., 2000	1.3% Non-significant	
Dagupta, Siddarth and Silva-Risso (2007)	NMNL	Survey, CA, 1999-2000		15.2%
Bento, Goulder, Henry, Jacobsen & von Haefen (2005)	NMNL	Survey, U.S., 2001	No direct estimate but MPG insensitive to price of gasoline	
Feng, Fullerton & Gan (2005)	NMNL	CES, U.S., 1996-2000	0.03% to 1.3%	
Klier and Linn (2008a)	Logit	Aggregate U.S., 1970-2007	Very approximately 69%	
Brownstone, Bunch & Train (2000)	Mixed NMNL Stated & Revealed Preference	CA Survey, 1993	132% to 147%	
Brownstone, Bunch, Golob & Ren (1996)	NMNL Stated & Revealed Preference	CA Survey, 1993	-420% to 402%	
Goldberg (1996, 1998)	NMNL	U.S. CES, 1984-1990	Consumers "not myopic"	
Goldberg (1995)	NMNL	U.S. CES, 1983-1987		
Vance & Mehlin (2009)	NMNL	Germany, Aggregate New Car Sales	Approximately 1,000%	
Cambridge Econometrics (2008)	Mixed logit	UK survey, 2004 to 2009	196% but uncertain of estimate. Authors contacted for clarifications.	
Eftec (2008)	NMNL	UK 2001 to 2006	TBD – authors contacted for clarifications.	
Fan & Rubin (2009)	Hedonic Price	State of Maine, 2007	Cars: 25% Lt. Trucks: 16%	Cars: 37% Lt. Trucks: 77%
Fifer & Bunn (2009)	Hedonic Price	U.S., 1996-2005	Cars: 52%, Pickups: 283% SUVs: 44%, Vans: 240%	
McManus (2007)	Hedonic Price	U.S., 2002	90%	
Espey & Nair (2005)	Hedonic Price	U.S., 2001	109%	
Arguea, Hsiao & Taylor (1994)	Hedonic Price	U.S., 1969 to 1986	3% to 46%	
Bhat & Sen (2006)	Choice model	San Francisco Bay Area, 2000	Elasticities of vehicle choice with respect to fuel costs 2% to 3% of purchase price elasticities.	

Sallee, West & Fan (2010)	Price Regression	Aggregate U.S., Used Cars, 1978-2009	79%, not statistically different from 100%
Langer & Miller (2008)	Price Regression	U.S., 2003 to 2006	Approx. 15% of PV of fuel cost changes reflected in vehicle price changes.
Busse, Knittel & Zettelmeyer (2009)	Price Regression	U.S., 1999 to 2008	Transaction prices adjust by 1.2 years worth of fuel savings for new cars.
Kilian and Sims (2006)	Price Regression	Aggregate U.S., Used Cars, 1978-1984	11% to 25%
Li, Timmins & von Haefen (2009)	Vehicle sales by fuel economy quantile	U.S. Metro Areas 1997 to 2005	Short-run price elasticity of MPG with respect to sales mix +0.02, long-run +0.2.

Hedonic price studies also disagree. Fan and Rubin estimate very high implicit discount rates for consumers in the state of Maine: 37% for car buyers, 77% for purchasers of light trucks. McManus' (2007) results indicate that consumers undervalue fuel economy by 30%, or less, depending on assumptions. Espey and Nair (2005) find very low implied discount rates, 1% to 4% for most of their models. Arguea, Hsiao and Taylor (1994) produce estimates of willingness to pay that range from 5% of expected present value to 46%, depending on the year.

Using other methods Bhat and Sen, 2006 found that consumers undervalue fuel economy by up to an order of magnitude. Evidence from Langer and Miller (2008) and Busse, Knittel and Zettelmeyer (2009) is more difficult to interpret but tends to indicate that consumers either undervalue fuel savings or value it at close to its expected present value.

Key attributes of the 28 studies are summarized in Table 13. Less than half of the studies were published in peer reviewed journals. Most of those in manuscript form are very recent (2008-2010) and are likely to be published soon. Four are reports and one a thesis. There is a relatively even distribution among the model types: 5 aggregate discrete choice, 12 disaggregate discrete choice (only 9 are U.S. studies and three of these are slightly different versions of the same study, leaving 7 different U.S. studies), 5 are hedonic price analyses, 3 are asset price models with two using other modeling frameworks. Six studies use aggregate sales or sales shares as the dependent variable, 11 use individuals' vehicle choices from surveys, 9 make new or used vehicle prices the dependent variable, and two use sales by fuel economy quantile. There is a similarly wide array of survey, aggregate sales, and vehicle price data sources. Some studies are based on a single year's data, others make use of data covering decades. The time periods range from the 1970s to 2009.

Fuel economy appears in a variety of forms, most commonly fuel cost per mile or fuel consumption per mile. Only one study, however, tested the hypothesis that markets might respond asymmetrically to rising and falling fuel prices. That study concluded that they do. This subject is worthy of further attention, since there is evidence that markets in other areas respond asymmetrically to petroleum price increases and decreases. In addition, it is possible that consumers respond differently to fuel economy than they do to fuel prices. There is evidence that vehicle travel responds differently to fuel costs than to miles per gallon (Small and van

Table 13. Summary of Key Features of 27 Econometric Studies

Study	Publication Status	Model	Dependent Variable	Type of Data	Time Period	Fuel Economy Measure	Price Expectations	Transaction Prices?	Heterogeneour Tastes?	Simultaneous Supply & Demand	Fuel Economy Standards Included?	MPG Value*
Berry, Levinsohn & Pakes 1995	Journal	NMNL	Sales shaes	Aggregate U.S.	1971-1990	Miles/P_g	Random Walk	No	Yes	Yes	No	—
Allcott & Wozny 2009	Manuscript	NMNL	New & used vehicle prices	Aggregate U.S.	1999-2008	Disc. PV of Fuel Cost	RW + alternatives	Yes	No	Yes	n.a.	—
Klier & Linn 2008	Manuscript	Logit	New vehicle shares	Aggregate U.S., monthly	1970-2007	Disc. PV of Fuel Cost	Random Walk	n.a.	Yes	No	No	0
Gramlich 2008	Manuscript	NMNL	New vehicle shares	Aggregate U.S.	1971-2007	P_g/MPG & MPG	Random Walk	No	No	Yes	Yes	+
Sawhill 2008	Manuscript	NMNL	New vehicle shares	Aggregate U.S.	1971-1990	Pg/MPG	ARIMA	No	Yes	Yes	No	+
Train & Winston 2007	Journal	Mixed Logit	Indiv. Vehicle Choices	U.S. Household Survey	2000	1/MPG	Static	No	Yes	Yes	n.a.	—
Dasgupta, Siddarth & Silva-Risso 2007	Journal	Mixed Logit	Indiv. Vehicle Choices	So. CA Vehicle Transactions	1999-2000	Pg/MPG	Static	Yes	Yes	No	n.a.	0
Bento, Goulder, Jacobsen & von Haefen 2005 & 2008	Journal	Random Coef. Logit	Indiv. Vehicle Choices	Nat. HH. Travel Survey U.S.	2001	Pg/MPG	Static	No	Yes	No	n.a.	X
Feng, Fullerton & Gan 2005	Manuscript	NMNL	Indiv. Vehicle Choices	CES	1996-2000	Pg/MPG	Static	No	No	Yes	n.a.	—
Brownstone, Bunch & Train 2000	Journal	Mixed Logit	Indiv. Vehicle Choices	CA survey	1993	Pg/MPG	Static	Yes, via respondents	Yes	No	n.a.	+
Brownstone, Bunch, Golob & Ren 1996	Journal	NMNL	Indiv. Vehicle Choices	CA survey	1993	Pg/MPG	Static	Yes, via respondents	No	No	n.a.	0
Goldberg 1995	Journal	NMNL	Indiv. Vehicle Choices	CES	1983-1987	Pg/MPG	Static	No	Yes	Yes	Yes	0
Goldberg 1996	Report	NMNL	Indiv. Vehicle Choices	CES	1985-1990	Pg/MPG	Static	No	Yes	Yes	Yes	0
Goldberg 1998	Journal	NMNL	Indiv. Vehicle Choices	CES	1984-1990	Pg/MPG	Static	No	Yes	Yes	Yes	0
Cambridge Econometrics 2008	Report	Mixed Logit	Indiv. Vehicle Choices	UK Survey	2005-2006	£/100 km	Static	No	Yes	No	No	+
eftec 2008	Report	Mixed Logit	Indiv. Vehicle Choices	UK Survey	2004 & 2007	l/100 km & £/100km	Static	No	Yes	No	No	—
Vance & Mehlin 2009	Report	NMNL	New Vehicle Shares	Sales data, Germany	1995-2007	€/100 km	Static	No	No	No	No	+
Fan & Rubin 2010	Manuscript	2-stage hedonic	New vehicle prices	Maine, sales data	2007	log(MPG)	Static	No	Yes	Yes	No	—
Espey & Nair 2005	Journal	1-stage hedonic	New vehicle prices	U.S. vehicle data	2001	1/MPG	Static	No	No	No	No	0
McManus 2007	Journal	1-stage hedonic	New vehicle prices	U.S. vehicle data	2002-2005	Pg/MPG	Static	Yes	No	No	No	0
Fifer & Bunn 2009	Thesis	1-stage hedonic	New vehicle prices	U.S. vehicle data	1996-2005	1/MPG	Random Walk	No	Yes	No	No	—
Arguera, Hsaio & Taylor 1994	Journal	2-stage hedonic	New vehicle prices	U.S. vehicle data	1969-1986	MPG	n.a.	No	No	Yes	No	—
Killian & Sims 2006	Manuscript	Asset Price	Used Car Prices	U.S.	1978-1984	PV fuel costs	Random Walk +	No	No	No	No	—

Table 13. Summary of Key Features of 27 Econometric Studies (continued)

Study	Publication Status	Model	Dependent Variable	Type of Data	Time Period	Fuel Economy Measure	Price Expectations	Transaction Prices?	Heterogeneour Tastes?	Simultaneous Supply & Demand	Fuel Economy Standards Included?	MPG Value*
Bhat & Sen 2005	Journal	MDCEV random utility	Individual vehicle choice	Survey: San Francisco, CA	2000	Pg/MPG	Static	Price not included	Yes	No	No	—
Langer & Miller 2008	Manuscript	Asset Price	New vehicle prices	U.S. regions weekly	2003-2006	Pg/MPG	Random Walk +	No	Yes	No	No	—
Busse, Knittel & Zettelmeyer 2009	Manuscript	Sales shares by quartile	New & Used vehicle prices	Sample, U.S. transactions	1999-2008	MPG Quartiles	RW	Yes	Yes	No	No	—
Li, Timmins & von Haefen 2009	Journal	Vehicle demand	Sales by Quantile	New & used sales in 20 U.S. metro areas	1997-2005	Pg/MPG & P_g	Random Walk	No	Yes	No	No	X
Sallee, West & Fan 2010	Manuscript	Asset Price	Used vehicle prices	Sample of U.S. auction transactions	1990-2009	Disc. PV of fuel costs	Random Walk +	Yes	Yes	No	No	0

* Indicates whether study generally implies that consumers undervalue (—), over-value (+) or equally value (0) fuel economy, or none of the above (X).

Dender, 2007; Greene 2010) and it would be interesting to see if vehicle purchases do also. The premise that consumers respond equivalently to a change in the price of fuel or a change in fuel use per mile is a logical consequence of the rational economic model, yet it may not actually reflect how consumers make decisions. It is a maintained hypothesis. If it is incorrect, then inferences about how consumers value fuel economy could be largely a reflection of a different kind of behavior: how consumers respond to fuel prices.

Although a variety of fuel price expectation models are employed, there is a clear preference for static expectations or random walk, both of which imply that current prices are the best predictor of future prices. Undoubtedly the fact that, historically, oil and gasoline prices are consistent with the random walk model (e.g., Hamilton, 2009) influenced analysts' decisions. Other models tested were models that implied that shocks would die away over time. While these models are reasonable from a statistical viewpoint, they may not match consumers' expectations. A possibly useful area for future analysis would be to explore models that allowed consumers to project trends into the future, or to base their expectations on learning from past price excursions.

Most studies did not have access to actual transaction prices and relied on manufacturer's suggested retail prices or other standard values. Very few studies attempted to explicitly estimate the effects of fuel economy standards on the market for fuel economy. In some cases, such as discrete choice models for a single year, this should not be a problem. In other cases, such as hedonic price models based on a times series, this could make it very difficult to identify the demand function. Many studies allowed preferences to vary across individual consumers or market segments. Methods of incorporating heterogeneity in preferences varied considerably, however. Some models estimate distributions of preference coefficients, others use dummy variables or interact consumer attributes with vehicle attributes. Many of the models use estimation methods appropriate for simultaneous determination of attributes (such as fuel economy) and their values. This is not necessary for all model formulations, however, and those not using simultaneous equation methods generally explain the assumptions that make it unnecessary (e.g., approximately fixed supply and attributes of used vehicles).

In the final analysis, however, none of these factors appears to be able to explain the different conclusions reached by the 27 studies. Given the variety of models, data and estimation methods, combined with the generally high level of technical expertise demonstrated by the researchers, one is led to look elsewhere for an explanation. In particular, fruitful areas to investigate appear to be the appropriateness of the classical rational economic decision making model for explaining consumers' fuel economy choices, and the difficulties of making statistical inferences given the complexity of the vehicle purchase decision.

Although a completely satisfactory explanation for these widely diverging results does not exist at present, several factors can be identified that clearly play a role in creating the confusion. First, and perhaps most importantly, Turrentine and Kurani's work has shown that real consumers almost certainly do not make their decisions according to the strict model of rational economic behavior. Instead, they found that households employed numerous, different decision rules. Many of the economic models reviewed in this report allow for heterogeneity of tastes; Turrentine and Kurani's work implies heterogeneity of decision rules, as well. This could be what causes estimates in mixed logit models to indicate no significant value of fuel economy on average, but significant variance across individuals. Certainly, the mere fact that vehicle use varies considerably across households would dictate a certain degree of variability in the value given to fuel economy. Heterogeneity of decision rules further complicates the question. Consumers may not be continuously trading off the multiple attributes of motor vehicles. Estimating models that imply that they are could lead to a misspecification bias.

Second, the choice of a motor vehicle is itself a complex problem. Vehicles have multiple attributes, many of which are difficult to define, let alone measure. Modelers cannot be expected to include all variables that are relevant, nor to measure them precisely in all cases. Style, reliability, prestige, and safety are examples of important vehicle attributes that themselves have many dimensions and are difficult to define and measure. These and other omitted or imprecisely measured attributes are likely to be correlated with fuel economy to a greater or lesser extent. The combination of omitted variables, errors in variables and correlated variables can easily lead to seriously biased coefficients. Most modelers do their best to deal with the problem with liberal use of fixed effects. This should help a great deal but may not be enough to prevent serious bias in the estimates of certain coefficients.

The literature on the economics of energy efficiency has only recently begun to appreciate that the consumer faces substantial uncertainty in making choices about the energy efficiency of energy-using durable goods. Uncertainty about future energy prices is the most obvious but may not be the most important source of uncertainty. Although vehicles are clearly labeled with fuel economy ratings, the credibility of the miles per gallon estimates is seriously questioned by many consumers. Moreover, as the label itself states, "your mileage may vary." Driving style, traffic conditions, trip lengths and even climate have significant impacts on realized fuel economy. There are also non-trivial uncertainties about vehicle use, vehicle lifetime, and the cost of increased fuel economy either in dollars or foregone other attributes. Uncertainty further complicates both consumers' decision making and quantitative inferences about it.

Vehicle fuel economy is primarily determined by two different processes. There is the consumer's choice among a set of vehicles with fixed attributes, and then there is the manufacturer's decision about how to design vehicles and which technologies to use. These are very different processes. Some studies are based solely on consumers' choices, while others attempt to combine the two. This in itself can lead to different inferences. Potentially even more important is the possibility that manufacturers' decision making and consumers' decision making about fuel economy may not be as perfectly synchronized as the rational economic model implies.

Key findings of this literature review can be summarized as follows:

1. Of the 25 distinctly different study estimates, 12 indicate that consumers significantly undervalue future fuel savings relative to a reference expected value based on average U.S. statistics, 8 indicate that consumers' values are approximately equal to the reference expected value, and 5 indicate that consumers significantly overvalue fuel savings.
2. With a very few exceptions, there are no obvious flaws in the methods or data used by these studies. This finding applies equally to the published and unpublished studies.
3. There does not appear to be an obvious explanation for the widely divergent results. Neither model type, formulation of the variable representing fuel economy, data type,

time period, nor any other readily identifiable factor shows a strong association with inferences about the values consumers place on fuel economy (Table 13).

4. The fifteen studies using discrete choice models are evenly divided between under, equal and over-valuing fuel economy; studies using hedonic price, asset price and other models more often indicate undervaluing (Figure 7).
5. The studies are also evenly divided between those dated 2008 or later (12) and those between 1994 and 2007. Six of the earlier studies and six of the 2008-2010 studies conclude that consumers significantly undervalue fuel economy. Seven of the earlier studies and six of the later studies imply that consumers roughly equally value or significantly over value fuel economy (Figure 8).
6. Price expectations are an important factor in all studies. Almost all of the studies assume that consumers will use the current price of fuel as a best estimate of future fuel prices, either due to static expectations or because they perceive fuel prices will follow a random walk. Five of the studies explore alternative price expectations models. However, none of the models allows consumers to project trends of increasing or decreasing prices into the future. Given the importance of price expectations to the evaluation of future fuel savings, a better understanding of how consumers form price expectations might provide useful insights.
7. Most of the studies (15) represent fuel economy interacted with the price of fuel, generally as fuel cost per mile. These studies are evenly divided between undervaluing (5), equally valuing (5) and overvaluing (5) (Figure 9). Six included fuel economy without interaction with the price of fuel, either as miles per gallon or gallons per mile. Of these, five found undervaluing and one equally valuing. Four calculated a discounted present value based on assumptions about vehicle lifetime, usage and fuel price expectations. These studies were evenly divided between undervaluing and approximately equally valuing. These differences suggest that there may be some insights to be gained by testing hypotheses about whether consumers respond differently to fuel price changes as opposed to fuel economy differences, or whether responses to the two variables are symmetric or asymmetric.
8. Several studies point out the empirical challenges to inferring the value of vehicle attributes to consumers: (1) correlations among attributes, (2) difficulties in defining and measuring the many relevant attributes, and (3) differences (heterogeneity) in tastes among consumers. These problems can lead to errors in variables and omitted variables and, together with correlations among variables they can result in seriously unstable, biased parameter estimates. More recent studies, exploiting massive data sets, have attempted to address these problems with detailed fixed effect coefficients and other methods. The continued differences in results suggest that even these efforts may not have successfully addressed the empirical challenges.

Fuel economy or CO_2 emissions standards are a core component of governments' policy strategies to address global climate change and energy security. Standards have been adopted by the United States, the European Union, Japan and China, among others. The annual costs and benefits of these standards easily amount to tens of billions of dollars. How consumers' value future fuel savings in making car buying decisions has been shown to be a crucial determinant of the economic consequences of such standards (Fischer et al., 2007). Yet surprisingly little is known about this vitally important subject.

Given the importance of understanding how the market values fuel economy and makes decisions about it, it might be worthwhile to convene top researchers with differing results to jointly investigate why those results differ so greatly. Such an effort would require sharing of data sets among researchers, who would then execute a mutually agreed upon set of statistical analyses, (1) to validate the results produced by others, and (2) to test a specified set of alternative model formulations using the different data sets. Such a structured test of model formulations against alternative data sets might lead to important insights about why apparently carefully and competently done analyses can lead to widely differing results.

It is at least as important to investigate the possibility that it is the rational economic consumer model that is incorrect. This line of inquiry might best be pursued through in two steps. First, conduct more in-depth interviews, surveys and experiments, such as reported in the seminal paper by Turrentine and Kurani (2007), to discover what decision criteria and algorithms real consumers actually employ when considering fuel economy and valuing fuel savings. Second, test these alternative models using experimental methods and empirical market data.

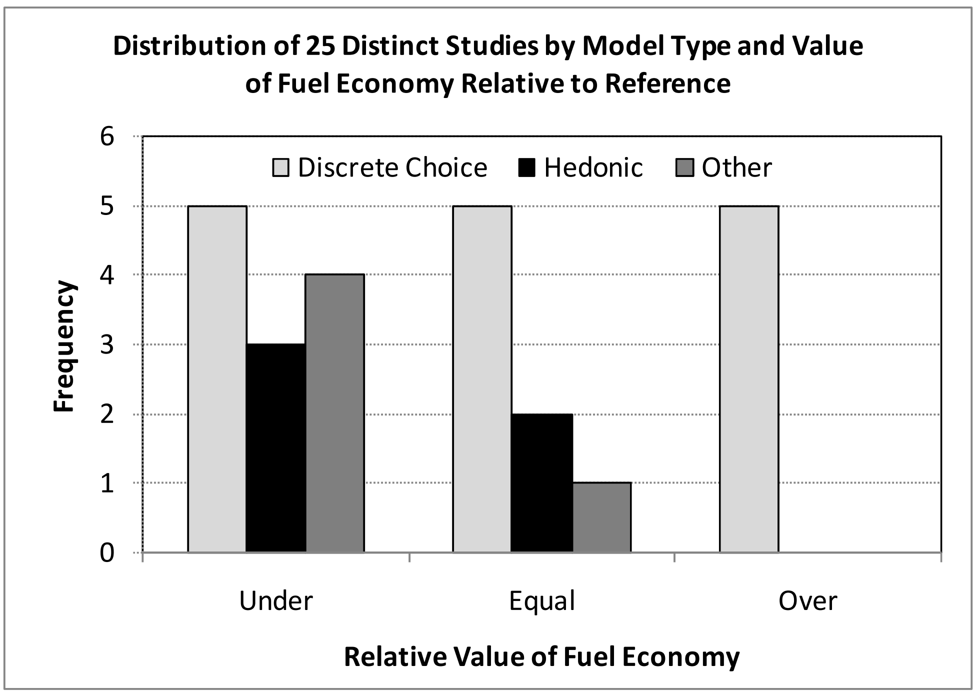

Figure 7. Distribution of 25 Distinct Studies by Model Type and Value of Fuel Economy Relative to the Reference Value.

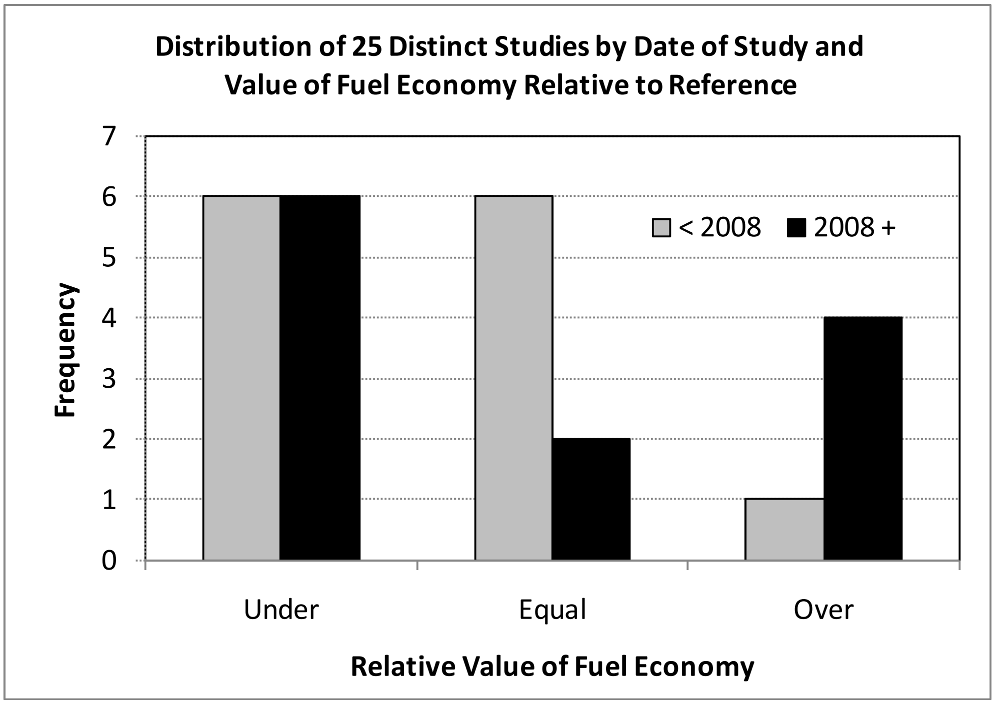

Figure 8. Distribution of 25 Distinct Studies by Date of Study and Value of Fuel Economy Relative to Reference Value.

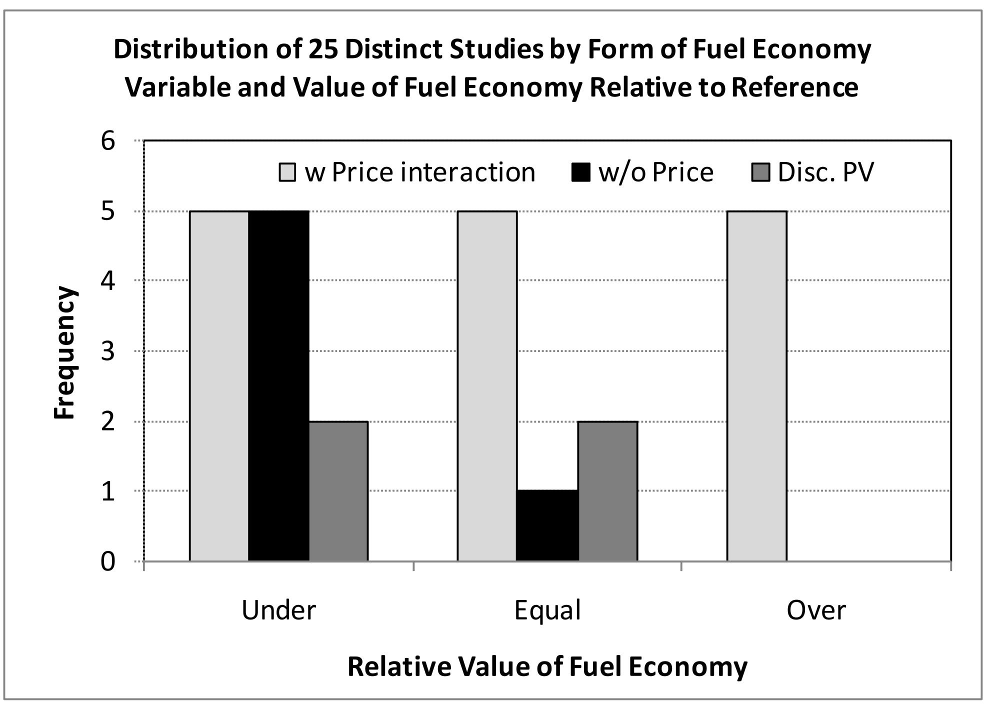

Figure 9. Distribution of 25 Distinct Studies by Form of Fuel Economy Variable and Value of Fuel Economy Relative to Reference Value.

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APPENDIX

REFERENCE ASSUMPTIONS ABOUT VEHICLE USE, LIFETIME AND DISCOUNTING

Most econometric studies that estimate the value of fuel economy in consumers' automobile choices represent vehicle price in dollars and fuel economy either as fuel cost per mile (dollars or cents per mile) or gallons of fuel per mile. To compare estimates from different studies on a common basis, it is necessary to have a standard set of assumptions about annual vehicle use, life expectancy and the discount rate. This allows one to compute expected discounted lifetime miles. Multiplying expected discounted lifetime miles times fuel cost per mile yields the expected discounted present value of future fuel savings.

The calculations used throughout this report rely on data produced by the National Highway Traffic Safety Administration (NHTSA, 2006). NHTSA's data, shown in Table A.1, are estimates of the average annual miles of use for passenger cars and light trucks by age. The same NHTSA document also provides estimated survival probabilities for the two vehicle types as a function of age. These were used to determine expected vehicle life. The median expected lifetime of a passenger car in the United States was estimated at just over 13 years for passenger cars and just over 14 years for light trucks. In the calculations below, we assume an average expected lifetime of 14 years for both vehicle types.

A real discount rate of 7% per annum is used throughout. The following discounting formula was applied to produce the estimates in Table A.1.

$$Expected \quad Discounted \quad Lifetime \quad Miles = \sum_{a=1}^{14} \frac{M_a}{\left(1+0.07\right)^{a-0.5}} \tag{A1}$$

The discounted lifetime miles are 112,600 for passenger cars and 125,891 for light trucks.

When fuel economy is represented as gallons per mile in a model, it is also necessary to assume a price of fuel. In all cases a constant fuel price has been assumed. Data for the year appropriate for the study in question are obtained from the Energy Information Administration's Annual Energy Review. That source provides prices in both current and constant dollars which are used as appropriate to the study.

Table A1. Annual Miles and Discounted Miles for Light-Duty Vehicles

Vehicle Age (Years)	Discounting Factor	Passenger Car Miles	Passenger Car Disc. Miles	Light Truck Miles	Light Truck Disc. Miles
1	0.96674	14,231	13,758	16,085	15,550
2	0.90349	13,961	12,614	15,782	14,259
3	0.84439	13,669	11,542	15,442	13,039
4	0.78914	13,357	10,541	15,069	11,892
5	0.73752	13,028	9,608	14,667	10,817
6	0.68927	12,683	8,742	14,239	9,815
7	0.64418	12,325	7,939	13,790	8,883
8	0.60203	11,956	7,198	13,323	8,021
9	0.56265	11,578	6,514	12,844	7,227
10	0.52584	11,193	5,886	12,356	6,497
11	0.49144	10,804	5,310	11,863	5,830
12	0.45929	10,413	4,783	11,369	5,222
13	0.42924	10,022	4,302	10,879	4,670
14	0.40116	9,633	3,864	10,396	4,170
Total		168,853	112,600	188,104	125,891

Source: U.S. DOT/NHTSA (2006, tables 9 & 10).