Consumers' Willingness to Pay for Fuel Economy and Implications for Sales of New Vehicles and Scrappage of Used Vehicles:

An Analysis of Deficiencies in the Benefit-Cost Analysis of the *Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks*, 83 Fed. Reg. 42,986 (Aug. 24, 2018)

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October 21, 2018

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About the Author

David Greene is a Senior Fellow of the Howard H. Baker, Jr. Center for Public Policy and a Research Professor of Civil and Environmental Engineering at The University of Tennessee. In 2013 he retired from Oak Ridge National Laboratory with the rank of Corporate Fellow after a 36 year career researching transportation and energy policy issues for the U.S. Government, especially the Departments of Energy and Transportation. Dr. Greene has authored or co-authored three hundred professional publications including over one hundred articles published in peer-reviewed journals. His research has received awards from the Transportation Research Board, the Society of Automotive Engineers, the Association of American Geographers, Oak Ridge National Laboratory, the Department of Energy, and the University of Tennessee, and the International Association for Energy Economics. Dr. Greene has served on more than a dozen special committees of the National Academies and is currently a member of the Committee for the Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles. He is the only person to have served on all five National Academy committees on the Corporate Average Fuel Economy Standards and the fuel economy of light-duty vehicles convened since 1990. A member emeritus of the Transportation Research Board's standing committees on Energy and Alternative Fuels, Dr. Greene is also a Lifetime National Associate of the National Academies and recipient of the Transportation Research Board's 2012 Roy W. Crum Award. He was recognized by the Intergovernmental Panel on Climate Change for contributing to the award of the 2007 Noble Peace Prize to the IPCC. He holds a Ph.D. in Geography and Environmental Engineering from The Johns Hopkins University and degrees in Geography from the University of Oregon (MA) and Columbia University (BA).

About the Report

This report presents analyses of selected issues raised in the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, 83 Fed. Reg. 42,986 (Aug. 24, 2018) and the associated Preliminary Regulatory Impact Analysis (USDOT NHTSA, 2018). The SAFE Rule presents several proposals to relax the greenhouse gas emissions and corporate average fuel economy (CAFE) standards for model years 2020 – 2026, with a leading proposal to roll back to the levels set for 2020. This rollback to 2020 is the subject of this analysis. It would be a significant relaxation of the existing fuel economy standards for MY 2021, the existing greenhouse gas emissions standards, and the so-called "augural" standards for model years 2022 – 2026 (hereafter referred to collectively as the existing greenhouse gas emissions and existing CAFE standards). This report addresses the NPRM's analysis of how consumers value fuel economy, and its methods and models for predicting how the existing greenhouse gas emissions and CAFE standards would affect sales of new vehicles and the end of life or scrappage of used vehicles.

The analysis and findings in this report are chiefly based on my 41-years of research on transportation and energy policy issues in general, the impacts of fuel economy and greenhouse gas regulations in particular, and my knowledge of the pertinent literature. In addition to studying the relevant portions of the National Highway Traffic Safety Administration's (NHTSA) and the Environmental Protection Agency's (EPA) ''Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks'' (NPRM) and the U.S. Department of Transportation, NHTSA's Preliminary Regulatory Impact Analysis (PRIA) of the SAFE Rule, I reviewed numerous research papers, many of which are cited in the 67 references to this report. My report also draws on the my recent research in collaboration with RTI International for the U.S. Environmental Protection Agency that addressed Consumers' Willingness to Pay for Vehicle Attributes (Greene et al., 2018; USEPA, 2018) and my recent research sponsored by the Energy Foundation on "Impacts of fuel economy improvements on the distribution of income in the US", (Greene and Welch, 2018).[2] The original work in this report consists of the application of decades of study of these issues to the methods and analysis used by the Agencies to estimate consumer and market responses to fuel economy and greenhouse gas regulations. The analysis of how consumers value fuel economy in this report demonstrates how the insights of behavioral economics provide a coherent and cogent understanding of the issue in contrast to the confused and illogical approach followed in the NPRM and PRIA. I show how the Agencies' analysis not only fails to make use of the advances achieved by behavioral economics but is illogical even in the context of the theory of fully rational economic decision making. My original analysis of the Agencies' scrappage models was necessary to demonstrate that their statistical deficiencies render them inappropriate for making either inferences or predictions about the effects of vehicle prices and fuel economy on scrappage rates. This report also includes an original critical review of literature that was cited in the NPRM and PRIA as evidence of the "Gruenspecht" effect to show that the studies cited actually assumed the existence of the effect by incorrectly interpreting fuel economy cost functions developed by a National Research Council committee on which I served (NRC, 2002).

[2] The views expressed in this report are those of the author and not necessarily those of the institutions who sponsored his research.

Consumers' Willingness to Pay for Fuel Economy:
Implications for Sales of New Vehicles and Scrappage of Used Vehicles

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October 18, 2018

I. Summary

The National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) have proposed the ''Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks'' (NPRM). The preferred alternative in the NPRM would maintain the 2020 model year standards for Corporate Average Fuel Economy (CAFE) and tailpipe carbon dioxide emissions for passenger cars and light trucks through the 2026 model year. The NPRM addresses regulatory standards for light-duty vehicle fuel economy and greenhouse gas emissions standards. To correctly evaluate the costs and benefits of the fuel economy and greenhouse gas regulations, it is essential to understand how consumers' and producers' behavior will differ in regulated and unregulated markets.

The NPRM's analysis of how consumers value fuel economy is fatally flawed because it neglects important insights from the field of behavioral economics, a sub-discipline of economics that has accounted for three Noble Prizes in economics since 2002. An accurate understanding of how consumers value fuel economy in their vehicle purchase decisions is essential to estimating the impact of the regulations on new vehicle sales and the prices and scrappage rates of used vehicles. The NPRM's analysis of how consumers value fuel economy is confused and illogical. As a consequence, it reaches erroneous conclusions about the benefits and costs of the existing and proposed regulations. This section summarizes the evidence supporting this conclusion presented in the remainder of this report.

Over the past 40 years, numerous studies, including four thorough, unbiased analyses by committees of the National Research Council (NRC) have found that at any given time technologies exist that could substantially and cost-effectively increase passenger car and light truck fuel economy, but that are not applied to new vehicles. The tendency of markets to neglect cost-effective energy efficiency technologies is known as the "energy paradox" and has been observed in energy using durable goods from light bulbs to refrigerators to motor vehicles. Behavioral economics, the discipline that studies systematic deviations from the theory of rational economic behavior provides a coherent explanation for the failure to adopt cost-effective energy efficient technologies, as well as an appropriate scientific basis for evaluating fuel economy and greenhouse gas standards.

Insights from behavioral economics are essential to understanding how the market for fuel economy actually works in the real world and for correctly evaluating the benefits and costs of fuel economy and greenhouse gas regulations. Neglecting these insights is a serious omission because, unlike the economic theories that underlie the evidence reviewed in the Notice of Proposed Rulemaking (NPRM),

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behavioral economics provides a coherent explanation of why consumers may undervalue the future fuel savings expected from an increase in fuel economy in some situations but not in others. The theory of rational economic behavior that underlies the great majority of the evidence reviewed in the NPRM fails to account for the fuel economy choices of real consumers. It assumes that consumers are fully informed, fully capable of making all relevant economic calculations and fully rational in their decision making. A groundbreaking study of how consumers actually make decisions about fuel economy found that none of the households interviewed had ever made their decisions as the model of rational economic behavior requires.

Over the past four decades, behavioral economics has established through repeatable experiments that real consumers behave in ways that systematically deviate from the rational economic agent model. Prospect theory, one of the most thoroughly studied and best established of those decision-making biases, describes how individuals make risky choices. The essence of prospect theory is that, faced with a risky choice, human beings typically weigh potential losses more heavily (about twice as heavily) as potential gains, a phenomenon known as loss aversion. The option to pay more upfront for a technology or group of technologies claimed to provide uncertain future fuel savings is just such a risky choice. Future fuel savings are uncertain because although every new vehicle has a rated fuel economy, the actual fuel economy an individual will obtain differs substantially depending on factors such as traffic conditions, driving style, trip length and temperatures. The unpredictability of gasoline prices adds to the uncertainty.

Researchers have applied the theory of loss aversion to the decision to buy or not buy a fuel economy technology, taking into consideration the sources of uncertainty. The results showed that consumers would behave as if they required payback periods on the order of two to three years, valuing less than one half of the expected value of fuel savings. The 2015 NRC report on fuel economy stated that manufacturers told the committee that consumers required technologies to pay back their additional cost in 1 to 4 years (the expected lifetime for a new car or light truck is 15 years or more). Four nationwide random sample surveys conducted between 2004 and 2013 presented consumers with simple choices to buy or not buy fuel economy technology. Their choices implied that, on average, consumers were willing to pay for 2 to 4 years of future fuel savings, consistent with the predictions of prospect theory and with manufacturers' perceptions.

Forty years of research have established that the framing of risky choices, how risky choices are presented, strongly influences whether or not decision makers will be loss averse. The decision to buy or not to buy a fuel economy technology is ideally framed to produce a loss-averse response. It is a simple choice to accept or decline a risky bet. On the contrary, complex choices in which many alternatives with many different attributes must be simultaneously considered are not framed to induce loss aversion. The decision to buy one of many different makes and models of new vehicles, or buy one of many different used vehicles or buy no vehicle, is not framed to induce loss aversion. When fuel economy regulations require manufacturers to improve the fuel economy of all vehicles incrementally over a long period of time, the improvements in fuel economy become common knowledge and the complex choices among vehicles consumers face are not framed to produce a loss averse response. As a result, consumers should be expected to fully value the fuel savings produced by fuel economy and greenhouse gas regulations when they purchase new vehicles and as they drive them.

The NPRM is thoroughly confused about how consumers actually value fuel economy. Behavioral economics provides a coherent explanation for consumers' decision making, based on decades of painstaking scientific research. Failing to take advantage of the advances in understanding real-world decision making by consumers, the NPRM has adopted an illogical and self-contradictory benefit-cost methodology that has produced an erroneous analysis of the effects of fuel economy and greenhouse gas regulations on vehicle sales, the turnover of the stock of used vehicles, and the associated economic, environmental and safety consequences.

II. Introduction

When fuel economy and greenhouse gas regulations require fuel economy improvements whose savings substantially exceed their cost, consumers understand that new vehicles offer greater value. As a result, sales of new vehicles and the rate of turnover of the stock of used vehicles will *increase*. The Notice of Proposed Rulemaking (NPRM) (USDOT, USEPA, 2018) fails to recognize this simple fact because it ignores insights about consumer decision making that have been established by economists and psychologists over the past four decades, and that are now widely accepted in both disciplines.[4]

Researchers have thoroughly documented systematic differences between actual consumers' behavior and the model of rational economic decision making that previously dominated economic analyses. A fundamental conclusion of this research is that consumers' decisions depend on how choices are framed; decisions and preferences are context-dependent. Among the most firmly established principles is loss aversion, the fact that faced with a risky choice, a choice with an uncertain potential for both loss and gain, human beings typically give potential losses approximately twice as much weight as potential gains.

The option to buy or not to buy a technology that improves fuel economy is framed as a simple risky choice in which "not buy" is the "do nothing" or "status quo" option. It is risky because while the present cost is known the future savings are uncertain. Future savings are meaningfully uncertain because they depend critically on future fuel prices and real-world fuel economy which can differ substantially from the official government rating. Loss aversion causes consumers to under-value the expected benefits of energy efficient technologies relative to their cost.

In contrast, fuel economy and greenhouse gas regulations require that all new vehicles be made more fuel efficient by the adoption of cost-effective technologies. There is no longer a simple risky choice. All vehicles have been made more fuel efficient and differ in numerous respects, many of which are more important to consumers than fuel economy. The context is no longer framed as a simple risky choice and loss aversion does not apply.

Because the Agencies fail to incorporate these important advances in economics in the NPRM's benefit-cost analyses, they adopt false premises and construct erroneous models. This leads the NPRM to incorrectly conclude that even fuel economy improvements that provide net savings to consumers will decrease new vehicle sales and slow the rate of turnover of used vehicles. Specifically:

1. Because the NPRM fails to acknowledge the importance of context and framing in consumers' choices, the Agencies are unable to reach a conclusion concerning how consumers value fuel

[4] Since 2002, three Nobel Prizes in Economics have been awarded for research in behavioral economics and behavioral finance: Daniel Kahneman, 2002; Robert J. Shiller, 2013; Richard Thaler, 2017.

economy. This leads them to implement an incoherent methodology for evaluating the impacts of fuel economy and greenhouse gas regulations on consumers' welfare and vehicle purchase decisions that contradicts their own assessment of consumers' willingness to pay for fuel economy.

2. The NPRM argues that the recent econometric evidence implies that consumers will value half, or more, to all of the expected present value of future fuel savings. However, the model they use to predict future new vehicles sales includes price increases due to fuel economy improvements but assigns no value whatsoever to the fuel savings those improvements produce. This illogical decision contradicts the Agencies' own assessment of the empirical evidence. Even if the value of fuel savings to consumers far exceeds the increased cost of fuel economy technology, the NPRM model will incorrectly predict that sales will decrease.
3. The NPRM also reaches erroneous conclusions about the impacts of the standards on used vehicle scrappage and the turnover of the stock of vehicles. In reality, consumers will recognize that new vehicles whose fuel savings substantially exceed their increased cost have greater value. The increased value of new vehicles relative to less efficient older vehicles will cause the prices of used vehicles to decrease increasing the rate of turnover of the stock of used vehicles. The increased rate of turnover of the vehicle stock will accelerate the rate at which advanced safety technologies penetrate the stock of vehicles in use.
4. The NPRM claims to have developed a statistical model of car scrappage that supports the view that the fuel economy improvements required by the augural standards will reduce the rate of stock turnover. In fact, the NPRM's excessively complex car scrappage model is fraught with serious statistical problems that include misspecification, multicollinearity and overfitting. As a result of these deficiencies the model cannot reliably predict the effects of new car prices or fuel economy on vehicle scrappage rates, nor can valid inferences about the effects of these variables be obtained from the model. The SUV and Truck scrappage models appear to have similar deficiencies.

Insights from the field of behavioral economics are essential to understanding how the market for fuel economy actually works in the real world and for correctly evaluating the benefits and costs of fuel economy and greenhouse gas regulations. Because they neglect these insights, the Agencies have produced a fatally flawed benefit-cost analysis.

The following sections provide a more complete explanation of how real consumers make decisions about fuel economy when purchasing motor vehicles, in contrast to the assumptions of the theories of rational economic decision making and expected utility theory (EUT). The systematic divergence of actual consumers' decision making from the rational economic model produces what has been called the "energy efficiency paradox", the observation that the market fails to adopt clearly cost-effective energy efficiency technologies. The attempt to force consumers' actual decision making about fuel economy into the rational economic framework leads to the NPRM's confusion about how consumers value fuel economy. The failure to understand how consumers value fuel economy leads to the construction and application of fatally flawed methods for predicting impacts on future sales of new vehicles and on the rates of turnover of the stock of used vehicles. In addition, the NPRM's scrappage models are invalidated by overfitting, misspecification and multicollinearity. These extremely serious methodological errors make it impossible for the Agencies' models to correctly estimate the benefits and costs of greenhouse gas and fuel economy regulations resulting in erroneous conclusions about the regulations' benefits and costs.

III. How Real Consumers Make Decisions about Fuel Economy

> "To a psychologist, it is self-evident that people are neither fully rational nor completely selfish, and that their tastes are anything but stable. Our two disciplines seemed to be studying different species, which the behavioral economist Richard Thaler later dubbed Econs and Humans." (Kahneman, 2012, p. 269) [5]

A manufacturer who offers consumers the option to buy or not buy a fuel economy technology is offering consumers a risky choice. The price of the technology is known but the fuel savings benefits over the life of the vehicle are uncertain. Not only do the benefits come in the future over a period of 15 years or so, but they depend on future fuel prices and real-world efficiency gains, both of which are substantially uncertain from an individual consumer's point of view. Loss aversion is the comprehensive and well-tested theory that when faced with risky choices, consumers typically consider potential losses approximately twice as important as potential gains (Kahneman and Tversky, 1979)[6]. As explained below, loss aversion has been documented in numerous scientific experiments reported in the peer-reviewed literature over the past four decades. In the context of a risky choice to buy or not buy a fuel economy technology, consumers will tend to undervalue future fuel savings by half or more relative to their discounted expected value over the life of the vehicle.

Psychologists have found that human beings have two different modes of processing information and making decisions: 1) an automatic system, also known as System 1 and, 2) an effortful, deliberative System 2. The Noble Prize-winning psychologist Daniel Kahneman describes the two systems as follows.

- "*System 1* operates automatically and quickly, with little or no effort and no sense of voluntary control.
- *System 2* allocates attention to effortful mental activities that demand it, including complex computations. The operations of System 2 are often associated with the subjective experience of agency, choice and concentration." (Kahneman, 2011, p. 21)

Kahneman further explains:

> "I describe System 1 as effortlessly originating impressions and feelings that are the main source of the explicit beliefs and deliberative choices of System 2." (Kahneman, 2011, p. 21)
>
> "When all goes smoothly, which is most of the time, System 2 adopts the suggestions of System 1 with little or no modification. You generally believe your impressions and act on your desires, and that is fine, usually." (Kahneman, 2011, p. 24)

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[5] Daniel Kahneman was awarded the Nobel Prize in Economics in 2002 for his work in behavioral economics including Cumulative Prospect Theory and loss aversion. His book cited here, *Thinking Fast and Slow*, won the National Academies' Best Book Award for 2012 (NAS, 2012).

[6] Weighing losses twice as much as gains is a typical or average loss averse response. Kahneman (2011) cites a range of 1.5 to 2.5, but there is even greater variation among individuals.

System 1 is loss averse (Kahneman, 2011, p. 281). Because System 1 is loss averse, consumers faced with a risky choice will be loss averse unless they make a deliberate, conscious effort to behave as rational economic agents.

Loss aversion has been shown to have important implications for public policy affecting energy efficiency and greenhouse gas emissions (e.g., Tsvetanov and Segerson, 2013). Heutel (2017) found that unrealized energy savings due to loss aversion could exceed the external costs of energy use. The value of energy savings is therefore a critical component of policies affecting energy efficiency. In the case of fuel economy and greenhouse gas regulations, the private value of fuel savings could exceed the social value of reduced greenhouse gas emissions, a result found by the existing rule (USEPA, 2012, tables 7.3-4, 7.3-5, 7.3-6 and 7.3-7). Allcott et al. (2014) proved that if consumers undervalue energy efficient technologies, taxing externalities alone would not produce an economically efficient result. Additional policies addressing the efficiency of energy using equipment (e.g., vehicles) were required.

The psychological principles of judgment and choice under uncertainty were combined into a coherent theory of choice under uncertainty by Kahneman and Tversky (1979) and have since been extensively studied and refined by psychologists and behavioral economists (e.g., see Dellavigna, 2009 for a literature review; Ert and Erv, 2013 for a recent survey and critique). This theory, known as Cumulative Prospect Theory (CPT) posits that decision making under risk is affected by four systematic biases:

1. Reference dependence, the tendency to evaluate outcomes relative to a reference point, such as the status quo,
2. Loss aversion, the weighting of losses relative to the reference point more heavily than gains,
3. The overweighting of low probability events and underweighting more likely outcomes and,
4. The tendency to be risk-averse in the domain of gains but risk-seeking when attempting to recover from a loss.

The most important biases with respect to choices about energy efficiency are the first two. Reference dependence implies that the effect of loss aversion will depend on the context of the choice. Häckel et al. (2017) applied CPT to decisions about investments in energy efficiency and quantified the relative impacts of the four factors via sensitivity analysis. His findings demonstrated that of the four components of CPT, loss aversion and reference dependence have by far the greatest impacts on consumers' energy efficiency choices.[7] Reference dependence is inherent in loss aversion because it is the direction of change from a reference point (generally the status quo) that defines losses and gains.

The existence of loss aversion in consumers' decision making has been repeatedly verified in controlled experiments (Dellavigna, 2009). It has even been detected in neuroimaging of brain activity in dopaminergenic regions and their targets (Tom et al., 2007).

> "The present study replicates the common behavioral pattern of risk aversion for mixed gambles that offer a 50/50 chance of gaining or losing money and shows that this pattern of behavior is directly tied to the brain's greater sensitivity to potential losses than gains. These results provide

[7] "Third, by implementing the modular elements of CPT, we can conclude that loss aversion is the major driver of the EE gap. Our results indicate that other elements of CPT such as probability weighting, have a rather negligible influence. As an exception, however, we find the determination of the reference-point to be very important. Depending on how the EE investment is framed, or perceived by the decision-maker, the EE gap might vanish or be amplified." (Häckel, et al., 2017, p. 424)

> evidence in favor of one of the fundamental claims of prospect theory, namely that the function that maps money to subjective value is markedly steeper for losses than gains." (Tom et al., 2007, p. 517).

Heutel (2017) conducted a choice experiment in an online survey to determine the effect of loss aversion on consumers' choices of energy efficiency options, including efficient lighting, programmable thermostats and energy audits.

> "Empirically, I find evidence that prospect theory explains people's investments (or lack thereof) in energy efficiency." (Heutel, 2017, p. 4)

In addition, Heutel (2017) found that the private benefits (the energy savings) from correcting the "market failure" of loss aversion exceeded the value of the reduced external costs from excessive energy use, indicating the importance of energy savings in assessing the costs and benefits of policies directed at improving energy efficiency.

> "Simulation results suggest that the behavioral market failure from loss aversion can be quite large relative to the market failure from the externality." (Heutel, 2017, p. 5)

Heutel (2017, p. 25) concluded that both his empirical and theoretical results pointed to the importance of incorporating CPT into energy policy evaluation and design, precisely what the NPRM has neglected to do.

Loss aversion has been applied to consumers' decisions to purchase fuel economy technologies for light-duty vehicles and shown to predict undervaluing of discounted expected fuel savings by half or more (Greene, 2011; Greene et al., 2013). Uncertainty about future fuel prices was based on historical gasoline prices and uncertainty about real world fuel economy was based on the real-world experience of thousands of motorists (Lin and Greene, 2011).

Loss aversion not only explains why consumers will undervalue fuel savings in the context of a risky choice, it explains why consumers will not undervalue future fuel savings in the context of comprehensive fuel economy and greenhouse gas regulations. Integral to the concept of loss aversion is context dependence, the fact that loss aversion is induced by the framing of choices (Tversky and Kahneman, 1981; Novemsky and Kahneman, 2005). In routine market transactions in which risk is not an important factor, Tversky and Kahneman (1991) assert that there is no loss aversion. But when consumers' purchases involve a risky choice, loss aversion should be expected.[8] Since the development of Cumulative Prospect Theory, researchers have continued to investigate which contexts are and are not framed to induce a loss averse decision. Novemsky and Kahneman (2005) were among the first to identify situations in which loss aversion would and would not apply.

> "Although early work finds loss aversion to be ubiquitous, applying to many types of goods and risks, it is important to note that there are limits to loss aversion." (Novemsky and Kahneman, 2005, p. 127)

[8] In riskless choices, loss aversion has been applied to explain the endowment effect, an observed difference between individuals' willingness to pay and willingness to accept (Horowitz and McConnell, 2002). The energy efficiency paradox, on the other hand, is concerned with how consumers value an initial payment of money for a more energy efficient version of a durable good that yields future monetary savings from reduced energy use.

> “The results from the current studies suggest that loss aversion is highly sensitive to the context in which the decision is made. People exhibit loss aversion in certain situations, but not in others. (Ert and Erev, 2013. P. 216)

Loss aversion does not apply in normal market transactions but only to purchases involving explicit risk.

> “First, there is no loss aversion for money that is given up in a purchase. This was supported by the similarity of choosing and buying prices. If there were loss aversion for the money that buyers give up, we would expect buying prices to be approximately half of the CE[9] set by choosers. This conclusion is also supported by the finding that loss aversion can be induced for money that is given up in an exchange if that exchange is a risky exchange.” (Novemsky and Kahneman, 2005, p. 123.)

> “Risky buyers are in a similar situation to that of buyers, except that they face a risky decision rather than a riskless one. Because risky buyers are gambling their money, we expect loss aversion for that money.” (Novemsky and Kahneman, 2005, p. 121)

Subsequent research has further clarified the types of risky choices that do and do not induce loss aversion (e.g., Gal and Rucker, 2018; Ert and Erev, 2013). Researchers have found that individuals are more likely to decline a gamble when it is framed as the alternative to doing nothing, i.e., the status quo (Ert and Erev, 2013). Loss aversion is more likely when the risky choice in question is not frequently encountered; repeated experience with a specific risky choice tends to reduce loss aversion (Erev et al., 2017, p. 372). This appears to be because loss aversion is associated with fast, intuitive decision making rather than slower, deliberative decision making (Kahneman, 2011). Factors strongly conducive to loss aversion are the perception of the choice as an action (accepting the bet) versus inaction (status quo), and gambles that involve higher versus lower stakes (Kahneman and Tversky, 1979, p. 279).

> “The results highlight two conditions that seem to trigger absolute loss aversion: the presentation of the risky options as an alternative to the status quo, and the use of high nominal pay-off magnitudes.” (Ert and Erev, 2013, p. 215)

This research has produced a more precise description of the context of consumers’ purchases in which loss aversion occurs.

- Consumer purchases involving risky choices,
- The presentation of the choice as a buy (accept the risky choice) or not-buy (decline and keep the status quo),
- The pay-offs (both gains and losses) are relatively large numbers (e.g., $100s or $1,000s),
- Choices that are made infrequently with little or no feedback to the decision maker.

The choice to buy or not buy a fuel economy technology or a bundle of fuel economy technologies in a new vehicle fits all four criteria well. Uncertainty about real-world fuel economy and future fuel prices make the decision substantially risky. The offer to buy or not buy a novel fuel economy technology is a simple risky choice that frames the do-not-buy option as the status quo. Changes to engines (e.g., diesel, hybrid, turbo-charging and downsizing) or transmissions (e.g., continuously variable transmission) or

[9] CE = choice equivalent, the minimum amount of money for which choosers prefer receiving money to receiving the good.

substantial materials substitution (aluminum for steel auto-bodies) are likely to be priced in the hundreds to thousands of dollars at the retail level. Finally, new car purchases are infrequent; the average length of time a household holds onto a given vehicle is estimated to be 6.6 years (Walsworth, 2016; Statista, 2018). Obtaining meaningful feedback requires effort because fuel economy naturally varies with such factors as traffic conditions, trip lengths, speed and temperature. And although households could conceivably quantitatively evaluate fuel economy technology decisions, even infrequently, the research available on the subject indicates that they do not do so (Turrentine and Kurani, 2007). System 1 decision making predominates.

The importance of framing in risky choices implies that consumers are not likely to make all fuel economy decisions in the same way, and that not all fuel economy choices will induce loss aversion. The four framing criteria imply that the following three types of fuel economy choices will be made differently and only the first will reliably induce loss aversion.

1. The choice to purchase or not purchase a fuel economy technology matches on all four points and is expected to induce loss aversion.
2. The choice, motivated by changes in fuel prices, among makes, models and model years with many different attributes, of which fuel economy is only one, is much less likely to induce loss aversion because it involves comparisons of vehicles on many attributes rather than a simple buy vs. do-not-buy choice.
3. The choice to buy or not to buy a particular new vehicle when fuel economy regulations are gradually increasing the fuel economy of all new vehicles is a complex choice involving numerous vehicle attributes, one that is not normally chiefly motivated by fuel economy, and there is no well-defined status quo option. Loss aversion about fuel economy should not be expected.

Cumulative Prospect Theory and, more specifically loss aversion and reference dependence explain why the market for fuel economy will undervalue future fuel savings relative to discounted expected savings when consumers choose between buying or not buying fuel economy technologies. CPT also explains why technologies that could cost-effectively improve fuel economy go unused. CPT also explains why consumers should be expected to fully value fuel savings in the entirely different context of purchasing new vehicles subject to fuel economy and greenhouse gas regulations. This central theory of behavioral economics explains the energy efficiency paradox, manufacturers' perceptions of consumers' willingness to pay for fuel economy technologies, as well as consumers' own statements about willingness to pay for fuel economy technologies based on repeated nationwide random sample surveys.

IV. Additional Evidence for Loss Aversion in Fuel Economy Decisions

Automobile manufacturers believe that consumers' willingness to pay for technologies that can improve fuel economy is only a fraction of the discounted, expected fuel savings over the life of the vehicle. Automakers' insights are relevant because they have been selling mass-produced vehicles to consumers for more than a century.[10]

[10] The Ford Model T was introduced in 1908.

> "During its information-gathering process, the committee found that auto manufacturers perceive that typical consumers would pay upfront for only one to four years of fuel savings, a fraction of the lifetime-discounted present value." (NRC, 2015, p. 315)

Requiring a short payback period is the same as requiring that the payoff (the fuel savings) far exceeds the potential loss (the upfront cost). Payback periods as short as 1 to 4 years correspond to weighing potential losses at least twice as much as potential gains. The automakers' perceptions reported by the National Research Council committee are entirely consistent with a loss averse response to a risky bet. They are also consistent with consumers' stated willingness to pay based on national random sample surveys.

Survey data reported in Greene (2011) and Greene et al. (2013) provide consistent evidence supporting manufacturers' perceptions. Participants in four 1,000-household random sample surveys (2004, 2011, 2012, 2013) conducted by ORC International, Inc. were asked to consider the next vehicle they planned to purchase or lease. They were then asked how much they would be willing to pay for a more fuel efficient engine, just as good in all respects as the one they were considering except that it would save them $400 per year on fuel. In the 2004, 2011 and 2012 surveys, respondents were randomly assigned either to the previous question (A) or were told that the engine would cost $1,200 and were asked how much it would have to save them in fuel each year before they would be willing to buy it (question B). The 2012 survey used a different engine cost ($1,900) and annual savings ($600). In the 2013 survey only question A was asked with an engine cost of $1,500. Individual answers varied but the mean calculated payback periods from the four surveys ranged from 2.6 to 3.5 years (Greene et al., 2013). Typical consumers weighed the potential loss (the cost of the better engine) more than twice as much as the potential gains (the annual fuel savings).

The undervaluing of fuel savings in the decision to buy or not buy fuel economy technology explains why engineering analyses (including the four National Research Council studies conducted since 1990) repeatedly identify cost-effective technologies capable of substantially increasing automotive fuel economy that are not taken up by the market. Five National Research Council (NRC) Committees have been convened to evaluate the potential of technologies to increase light-duty vehicle fuel economy and the Corporate Average Fuel Economy (CAFE) standards. All four that have completed their work found substantial potential to increase fuel economy at costs that were well below the expected present value of future fuel savings (NRC, 1992, 2002, 2011, 2015).[11] The NRC committees' findings concerning the potential to increase passenger car and light truck fuel economy and its costs, plus estimates for 1975 and 1980 based on a peer-reviewed literature review (Greene and DeCicco, 2000) are summarized by the fuel economy cost curves in Figure 1. Each curve is defined relative to vehicles representative of those available at the time the studies were conducted. Every curve starts with very low cost technologies and indicates substantial potential to increase fuel economy at costs much smaller than the present value of expected fuel savings. For example, a vehicle traveling 10,000 miles per year would save 100 gallons per year for a fuel economy increase from 20 to 25 miles per gallon. At $2.50 per gallon, the discounted lifetime value of fuel savings would be about $2,500.[12] Fuel savings of this magnitude would justify substantial increases in both passenger car and light truck fuel economy in every year in which the potential to increase fuel economy was assessed.

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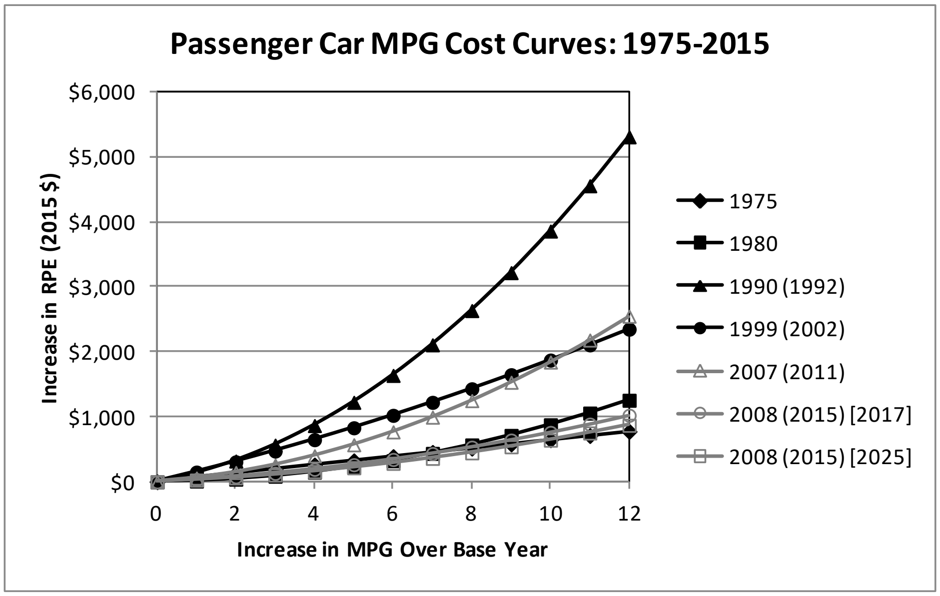
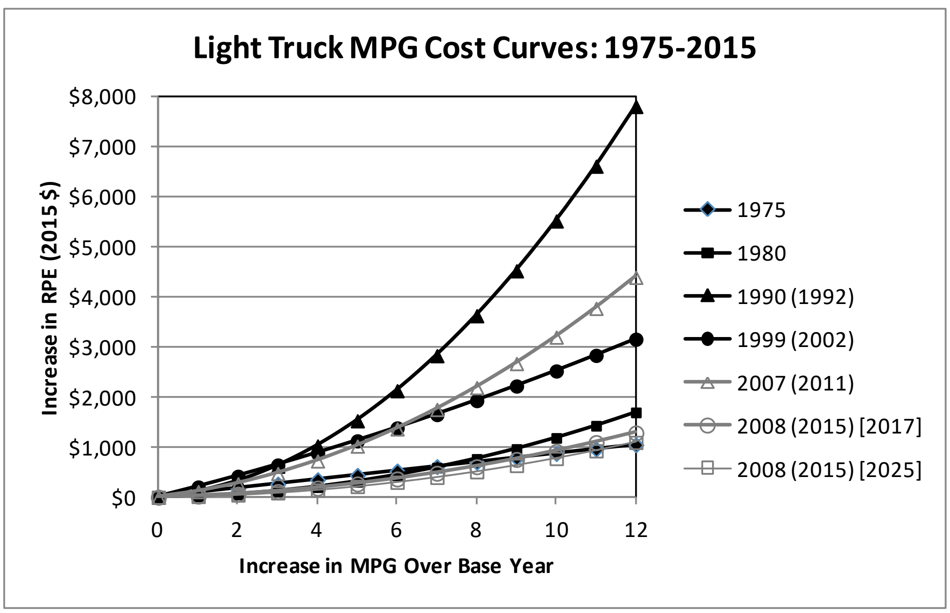
[11] The fifth committee's work is still in progress and no findings have been issued.
[12] Assumes a 6% annual discount rate and a 15-year vehicle lifetime.



Figures 1a. Passenger Car Fuel Economy Cost Curves. 1975-2025 (Greene and Welch, 2018).
RPE = Retail Price Equivalent, the estimated cost to the consumer. Curves are identified by the base model year vehicle, the year of the NRC report is shown in round brackets () and for the 2008 study the year in which the cost curve is estimated to apply is shown in square brackets [].



Figures 1b. Light Truck Fuel Economy Cost Curves 1975-2025 (Greene and Welch, 2018).
RPE = Retail Price Equivalent, the estimated cost to the consumer. Curves are identified by the base model year vehicle, the year of the NRC report is shown in round brackets () and for the 2008 study the year in which the cost curve is estimated to apply is shown in square brackets [].

Such results are evidence of the energy efficiency paradox or energy efficiency gap, the observation that many apparently cost-effective energy efficiency technologies are not adopted for use in energy using durable goods. The energy efficiency paradox has been a subject of discussion in energy policy for decades (e.g., Gerarden et al., 2015; Gillingham et al., 2014). A variety of possible explanations for the paradox have been proposed, ranging from incomplete analysis of options to imperfect information and bounded rationality to behavioral biases in decision making. Recent research has shown that loss aversion can explain most or all of the failure to adopt cost-effective fuel economy technologies (Greene, 2011 and 2013; Häckel et al., 2017; Heutel, 2017).

Integral to the concept of loss aversion is context dependence, the fact that loss aversion is induced by the framing of choices (Novemsky and Kahneman, 2005). This places the theory of loss aversion in sharp contrast to Expected Utility Theory (EUT), the theory of rational economic choice under uncertainty, according to which consumers are fully informed, full capable, rational economic agents whose choices are independent of context. Not only do these premises seem implausible on their face, a seminal study by researchers at the University of California showed that EUT does not correspond to the way real consumers make decisions about fuel economy.

V. **The Choices of Real Consumers are Not Consistent with Expected Utility Theory**

Expected Utility Theory (EUT) of individual preferences in the context of choices with uncertain outcomes asserts that the subjective value, V, associated with a risky choice is equal to the statistical expectation of the potential outcomes of the gamble. Faced with a risky decision with i=1 to n > 1 possible outcomes, x_i , having values, *V(y,x)* where y_0 is an initial level of wealth, each with probability $p(x_i)$, a risk-neutral decision maker will determine the value of the decision by the sum of the probability weighted outcomes (Equation 1).

$$V(y,x) = \sum_{i=1}^{n} p(x_i)v(y_0 + x_i) \tag{1}$$

According to EUT, risk-neutral decision makers' willingness to pay for future fuel savings is equal to their discounted expected value over the life of a vehicle. A common definition of willingness to pay is the maximum amount of money a consumer will give up to obtain a good or avoid a bad (e.g., Varian, 1992). Assuming a constant discount rate, *r*, the present value of future savings, *S*, can be calculated by integrating the rate of fuel savings per time, *t*, multiplied by the discounting function, integrated over the life expectancy, *L*, of the vehicle. The rate of fuel savings depends on the difference in fuel use per mile (*1/mpg*), multiplied by miles driven, m_t, and the price of gasoline, P_t . The difference in fuel use per mile is equal to the difference of the inverses of the reference miles per gallon, mpg_0 , and the increased miles per gallon $mpg_0+\Delta$.

$$S = \int_{t=0}^{L} m_t P_t \left(\frac{1}{mpg_0} - \frac{1}{mpg_0+\Delta}\right) e^{-rt} dt \tag{2}$$

The net value of the decision is the savings from increased fuel economy minus the upfront cost, *C*: *S-C*.

Equation 2 helps understand why the net value of future fuel savings is uncertain. First, while every vehicle has an official mpg rating provided by the Environmental Protection Agency and Department of Energy, the rating comes with a warning:

> "Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle." (https://www.fueleconomy.gov/feg/Find.do?action=bt1)

Consumers are aware that real world fuel economy is likely to differ substantially from the government's ratings. A recent analysis of on-road fuel economy estimates reported by vehicle owners found a two-standard deviation confidence interval of +49% to -33% around the rated value (Greene et al., 2017). There is also evidence that the deviations from rated fuel economy for vehicles in the same household are very weakly correlated (Wali et al., 2018), indicating that the shortfall a consumer experiences with one vehicle is not necessarily a good predictor of the shortfall that will be experienced with another. Consumers understand this uncertainty. A random sample of 1,000 U.S. households were asked what mpg they would expect to attain for a vehicle rated at 25 mpg, as well as the best and worst mpg they would expect get with that vehicle. The average expected mpg was 22.9 and the average range from worst to best was 8 mpg (Greene et al., 2013).

The future price of gasoline (P_t) is uncertain because it is primarily determined by the price of petroleum. Hamilton (2009) showed that historical petroleum prices were not statistically different from a random walk, a series of unpredictable changes. Based on two-decades of surveys of consumers' expectations of future gasoline prices, Anderson et al. (2013) concluded that average consumer beliefs were indistinguishable from a no-change forecast, the best possible forecast for a variable following a random walk. Other parameters of equation 2 are also uncertain. Miles traveled (m_t), vehicle life (L) and even discount rates (r), to the extent they are influenced by inflation and market rates of return, will also vary to some degree.

As a descriptive theory of decision making, expected utility theory implies that consumers will integrate equation (2) taking into account the probability distributions of the key parameters, and base their decisions on its expected value. Few would claim that car buyers actually make such calculations (Schoemaker, 1982). However, it is sometimes argued that they may be able to intuitively approximate the value of savings with reasonable accuracy. Furthermore, consumers can obtain estimates of the present value of fuel savings from other sources. Yet in-depth interviews of households concerning their car-buying decisions (discussed in greater detail below) found that they did none of these things (Turrentine and Kurani, 2007).

Expected utility theory recognizes that decision makers may be risk averse (which is not the same as loss averse) and may weigh losses more than gains, but EUT cannot account for the magnitude of undervaluing predicted by loss aversion. Noting that decreasing marginal utility of income (the idea that one more dollar increases the happiness of a poor person more than that of a rich person) is the sole explanation for risk aversion in EUT, Rabin (2000) demonstrated mathematically that EUT cannot plausibly account for loss aversion in gambles of \$10, \$100, \$1,000 or even more. The reason is that in the EUT framework, any utility function with decreasing marginal utility of income that predicts even very little risk aversion over modest stakes implies an absurd degree of risk aversion for large stakes. For example, an expected utility maximizer who would always turn down a 50-50 bet of lose \$1,000 or gain \$1,100 would also turn down a 50-50 bet of lose \$10,000 or gain *any* sum up to and including an infinite amount.

Manufacturers' and consumers' statements about how quickly fuel savings must repay any additional cost are not consistent with the theory of economically rational decision making. Equation 2 can be used to calculate a payback period, the number of years it would take at a given rate of undiscounted annual fuel savings to equal S, the lifetime discounted present value of fuel savings. Let m_0 and P_0 be the annual miles driven and the price of gasoline in the first year of a vehicle's life. Assuming that miles traveled decrease exponentially with vehicle age, $m_t = m_0 e^{-\delta t}$, and that consumers expect future gasoline prices to be about the same as the current price and that fuel economy is relatively constant over the life of a vehicle (Greene and Welch, 2018), the payback period is given by equation 3.

$$Y = \int_{t=0}^{L} e^{-(\delta+r)t} dt = \frac{1}{(\delta+r)}\left[1 - e^{-(\delta+r)L}\right] \tag{3}$$

Plausible discount rates range from 3% to 10%, rates of decline in vehicle use range from 2% to 4% and expected vehicle lifetimes from 13 to 17 years depending on the type of vehicle (NHTSA, 2006; Davis et al., 2018). Given these parameters, a consumer requiring payback in 3 years would be valuing future fuel savings at between 26% and 48% of the discounted expected value. For a payback period of 2 years the implied range would be 17% to 33%, while a payback period of 4 years would imply that increased fuel economy would be valued at between 35% and 67% of expected lifetime savings. Yet manufacturers say consumers require payback in 1-4 years and the survey evidence indicates typical payback requirements of 2-4 years. Such short payback periods suggest that consumers substantially undervalue expected fuel savings when offered the choice to buy or not buy fuel saving technologies.

The only published study to document the actual fuel economy decision making processes of real households found no evidence of decision making consistent with the rational economic model. Real consumers relied on System 1 and not System 2 when making decisions about fuel economy. Turrentine and Kurani's (T&K) (2007) investigation of how consumers make fuel economy choices is unique because the researchers conducted extended interviews with households to elicit their actual decision making behavior. They interviewed 57 California households for approximately two hours each about their history of vehicle ownership and purchases. Six households were recruited by random sampling in each of ten lifestyle categories. The interviews began by listening to the household members talk about past vehicle purchases and their reasons for their vehicle choices. Next, they asked about the most recent vehicle purchase in greater detail. The third step was to ask the households to design the next vehicle they imagined themselves buying, referring to a table of attributes one of which was fuel economy. In the fourth phase they revealed their interest in fuel economy and asked questions about willingness to pay for a 50% increase in fuel economy to their imagined next purchase, and concepts such as payback periods.

T&K's (2007) findings with respect to the rational model of EUT were striking. Half of the households were unwilling or unable to offer a willingness to pay for the 50% increase in fuel economy. Only two individuals offered what the interviewers judged to be answers arrived at through a process that could be described as economically rational. Neither based their estimate on a net present value calculation (similar to Equation 3) but rather on payback periods and the assumption that gasoline prices would not change much in the future. This result is more surprising because three of the ten groups were comprised of 1) college or graduate students nearing graduation, 2) computer hardware or software engineers and 3) professionals in the financial services sector. The findings not only demonstrate that households do not think in terms of the EUT model but they also cast doubt on the notion that individuals might be able to arrive at the right answer through intuition or use of other sources of information.

> "We found no household that analyzed their fuel costs in a systematic way in their automobile or gasoline purchases." (Turrentine and Kurani, 2007, p. 1213)

> “One effect of this lack of knowledge and 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.” (Turrentine and Kurani, 2007, p. 1213)
>
> “It is clear that few households understand the financial calculations that lie behind questions about ‘an investment in fuel economy’ and payback periods, and that even those few do not apply such knowledge to their household vehicle purchase and use.” (Turrentine and Kurani, 2007, p. 1220)
>
> “In short, the consumers we spoke to do not think about fuel economy in the same way as experts, nor in the way experts assume consumers do.” (Turrentine and Kurani, 2007, p. 1221)

Attempts to use the rational economic agent model to infer consumers’ willingness to pay for fuel economy from market transactions have produced widely varying and inconsistent results. Evidence from the econometric literature has been reviewed by Greene (2010), Helfand and Wolverton (2011), USEPA (2018) and Greene et al. (2018). All found a wide range of estimates with no consensus that consumers either undervalued or overvalued fuel economy relative to its expected value. USEPA (2018) compared 117 estimates of the marginal WTP for a $0.01/mile reduction in a vehicle’s fuel cost derived from 52 U.S. studies covering the period 1995 to 2015 and concluded that the evidence was approximately equally divided between substantial undervaluing and approximately fully valuing relative to expected value.

The NPRM remains confused about how consumers value fuel economy because it fails to acknowledge the contributions of behavioral economics to understanding consumer decision making under risk. Noting that the peer-reviewed literature does not reach a consensus on the subject, the NPRM claims that three recent studies based on very large samples of individual transactions reflect a greater consensus and more support for the full valuation of expected future fuel savings. Three studies is a very small sample, nevertheless, on close examination, the NPRM’s claim turns out to be incorrect. Allcott and Wozny (2014) found that inferences about WTP for future fuel savings depended strongly on assumptions about how consumers anticipate future fuel prices. If expectations were based on oil futures prices, they estimated that consumers were willing to pay for about 76% of expected lifetime, discounted fuel savings. But if prices were assumed to follow a random walk or matched expectations from consumer surveys (the method supported by Anderson et al., 2011), consumers were willing to pay for only 55% or 51%, respectively. Undervaluing expected future savings by half is similar to requiring a simple payback of about 4 years for a vehicle with an expected lifetime of 15 years.

Using data on wholesale transactions, Sallee et al. (2016) found that buyers of used cars with odometer readings of 10,000 to 100,000 miles fully valued remaining fuel savings but that buyers of vehicles with 100,000 to 150,000 miles on their odometers were willing to pay for only about 30% of the present value of remaining fuel savings. U.S. passenger cars and light trucks reach 100,000 miles after about 7 years and approximately half of the light-duty vehicles on U.S. roads are more than seven years old (NHTSA, 2006). The implication is that about half of the used car market (the older half) severely undervalues future fuel savings while the newer half fully values them. Busse et al. (2013) estimated the effects of changes in the price of gasoline on new and used vehicle prices and concluded that there was little evidence in either the new or used car markets that consumers dramatically undervalued changes in expected future fuel costs.

Two other recent studies also reached different conclusions. Bento et al. (2016) also found evidence of undervaluing, indicating consumers value a $1 decrease in operating cost at between $0.22 and $0.96. A more recent study not mentioned in the NPRM analyzed survey data for over 500,000 new car buyers (Leard et al., 2017). They found that consumers would pay $0.54 for a $1 increase in present value fuel savings, almost identical to Allcott and Wozny's (2014) results assuming fuel price expectations consistent with a random walk or static expectations.

A critically important fact is that all of the recent studies analyze consumers' choices among different types of vehicles as a consequence of changes in the price of gasoline. The fuel economy choice is therefore embedded in a very complex choice among vehicles with many differing attributes. Such choices are not well framed to induce loss aversion with respect to fuel economy. They are not simple choices between accepting versus declining a risky bet. They are choices among numerous makes, models and model years of automobiles with differing attributes only one of which is fuel economy. There is no clear status quo choice. One might argue that not buying any vehicle could be the status quo, but the decision to buy or retain a vehicle is a complex, multi-dimensional choice rather than a simple choice about fuel economy. As Allcott and Wozny's (2012) results suggest, consumers' preferences are likely to be strongly affected by their expectations about future fuel prices. Because of these important differences in the framing of the choices, loss aversion is much less likely to come into play, although other departures from rational economic decision making may still be relevant and estimates may also vary with data sources and choices of statistical methods (Greene et al., 2018).

The choice among various vehicles differs from the choice to buy or not buy a fuel economy technology in another important way. Differences among new vehicles of a given model year are likely to embody similar levels of technology. Given similar technologies, differences in fuel economy among vehicles will primarily be due to differences in mass and engine power (Pagerit et al., 2006; Knittel, 2012).[13] Consumers tend to perceive fuel economy as a function of vehicle and engine size when choosing among vehicles with similar drivetrain technology.

> "When we ask our respondents to tell us what type of automobile comes to mind when we say 'good fuel economy', most think of the smallest, cheapest vehicles." (Turrentine and Kurani, 2007, p. 1218).

Consumers' intuition about vehicle size and fuel economy may reduce their uncertainty about fuel economy when choosing among vehicles of different sizes because size, mass and engine power are strongly correlated. A 10% reduction in the mass of a vehicle combined with an equivalent reduction in engine horsepower (thereby holding performance constant) reduces fuel economy by about 6.7%, on average (Pagerit et al., 2006). Associating fuel economy with vehicle and engine size is likely to reduce consumers' uncertainty about fuel economy differences between vehicles of different sizes.

Because fuel economy choices among types of vehicles may not induce loss aversion does not necessarily imply that consumers will make entirely economically rational decisions in those contexts. Decision making biases caused by bounded rationality and imperfect information (e.g., Turrentine and

[13] A vehicle's mass determines the physical work that must be done to accelerate a vehicle and to overcome the friction of rolling resistance. Mass is also correlated with a vehicle's frontal area, a key determinant of aerodynamic resistance. Finally, apart from a vehicle's mass, for vehicles with stoichiometric engines, engine size determines how much fuel is consumed per engine revolution.

Kurani, 2007), the potential lack of salience of fuel economy differences between similar vehicles, limited attention (Sallee, 2014), and lack of self-control probably all apply to some degree. Researchers have also demonstrated that consumers have an "mpg illusion": they tend to value changes in miles per gallon (mpg) equally regardless of the initial mpg (Larrick and Soll, 2008). Thus, a five mpg increase from 10 to 15 mpg weighs about as much as a 5 mpg increase from 25 to 30 mpg, even though the difference in fuel consumption per mile is five times as great for the improvement from 10 to 15 mpg.

VI. Loss Aversion Does Not Apply to Fuel Economy Improvements Required by Regulations

It follows from the findings of behavioral economics that consumers' evaluation of increased fuel economy will be dependent on the context of their choices.

1. The choice to buy or not buy a fuel economy technology or package of technologies is framed as a simple risky choice and will induce loss averse behavior.
2. Complex choices among existing vehicles with many varying attributes including fuel economy are much less likely to induce loss averse behavior.
3. Complex choices to buy or not buy one of many regulated new vehicles with many different attributes when the fuel economy of all vehicles is being similarly improved are not framed to induce loss averse behavior.

In the context of type 1 choices, consumers are likely to undervalue expected future fuel savings by half or more, consistent with the stated beliefs of automobile manufacturers as reported by the NRC (2015), and with the simulations presented in Greene (2011) and Greene et al. (2013). But when facing type 2 choices, it is not clear that undervaluation will be as severe and it may not be present at all. The relevant econometric literature analyzing choices from this perspective does not provide a consistent answer. For type 3 choices, the kind of choices faced by consumers when fuel economy and greenhouse gas regulations require regularly increasing fuel economy, undervaluing fuel economy is not indicated. Consumers' broad and enduring support for fuel economy standards and for raising fuel economy standards also supports this inference (e.g., NRC, 2015, table 9.2; CRSG, 2017 & 2018).

Finally, regardless of the choice context, there is no reason to believe that as consumers actually save money because of improved fuel economy the dollars they save are worth any more or less than other dollars available to them. The perceived decision utility at the time a choice is made may vary by the context but the experienced utility from increased income due to lower fuel costs will not (Kahneman and Sugden, 2005).

Therefore, in the case of fuel economy improvements due to regulation, future fuel savings are most appropriately valued at their discounted, expected value over the life of the vehicle.[14] It follows that the impact on sales of fuel economy improvements due to regulation should be based on the net value of the improvements measured by the full present value of expected fuel savings minus the cost of the improvements.

[14] In general, how to do behavioral welfare economics is unresolved (Bernheim, 2016). A special approach is not needed in the case of regulatory standards since the choice of vehicles under regulation is unlikely to induce loss aversion.

VII. The Method Used in the NPRM to Predict Impacts on Vehicle Sales is Illogical

The method used in the NPRM to predict the impacts of standards on new vehicle sales is contrary to both Cumulative Prospect Theory and Expected Utility Theory and contradicts previous assertions made in the NPRM about how consumers value fuel economy. The method is deficient in that while it includes vehicle price increases due to the adoption of fuel economy technologies it does not include any value for the fuel savings those technologies would produce. On page 43072 the NPRM asserts that the three recent studies that it has singled out for special consideration indicate that car buyers value a large proportion of expected future fuel savings.

> "These studies point to a somewhat narrower range of estimates than suggested by previous cross-sectional studies; more importantly, they consistently suggest that buyers value a large proportion – and perhaps all – of the future savings that models with higher fuel economy offer."

If consumers value "a large proportion" or "perhaps all" of future fuel savings when making their car buying decisions, estimating the impacts of fuel economy improvements on future sales based on increased cost but omitting the value of future fuel savings is not only illogical but contradictory to the NPRM's own assertions.

The recent econometric studies cited in the NPRM correctly assert that consumers consider both fuel economy and vehicle price in making vehicle purchase decisions. All three studies (as well as Leard et al., 2017, cited above) use a model consistent with that of Allcott and Wozny (2014), which specifies that consumers trade-off vehicle price and fuel savings when making their purchase decisions. The Allcott and Wozny (2014, pp. 782-783) model assumes that a consumer's utility (*u*) is a function of the consumer's income (*w*), the price of the vehicle (*p*) and the present discounted value of future gasoline costs over the vehicle's remaining life (*G*). The parameter η is the marginal utility of a dollar, and *w*, *p* and *G* are all measured in present value dollars. Following Allcott and Wozny's notation, *j* indexes models of vehicles, *a* indexes vehicle ages, and *t* indexes time periods.

$$u_{jat} = \eta\left(w_i - p_{jat} - \gamma G_{jat}\right) \tag{4}$$

The fraction of future fuel costs that affect the consumer's utility is measured by *γ*, and *γ*✕100% is the metric discussed in the NPRM as the percent of future fuel costs incorporated into vehicle purchase decisions (NPRM, p. 43072). Note that in Allcott and Wozny's (2014) analysis, *j*=0 indicates the option not to own a vehicle, which means that the trade-off between fuel costs and vehicle price affects vehicle sales.

Formulations similar to equation 4, in that they include an explicit trade-off between vehicle price and present value fuel costs, are used in nearly all economic analyses of consumers' car-buying decisions. The 52 papers published between 1995 and 2015 reviewed by USEPA (2018), the most comprehensive analyses to date of willingness to pay for vehicle attributes, produced 122 estimates of willingness to pay for fuel cost reductions. After vehicle price, fuel cost was the most commonly included variable in all the models reviewed and was included in the great majority of models. All these models assumed that the value consumers perceive in vehicles includes trading off vehicle price and fuel costs (and therefore increases in vehicle prices and fuel savings). Standard methods of economic analysis and the overwhelming weight of the literature on how consumers evaluate vehicles and make vehicle choices (including to buy or not to buy) recognize that both vehicle price and fuel costs are important to consumers' purchase decisions.

The NPRM attempts to justify excluding the value of fuel cost savings in its new vehicle sales model by noting that its statistical model of vehicle sales was not improved by including fuel costs.

> "The analysis was unable to incorporate any measure of new car and light truck fuel economy in the model that added to its ability to explain historical variation in sales, even after experimenting with alternative measures of (sic) such as the unweighted and sales-weighted averages (sic) fuel economy of models sold in each quarter, the level of fuel economy they were required to achieve, and the change in their fuel economy from previous quarters.
>
> "Despite the evidence in the literature, summarized above, that consumers value most, if not all, of the fuel economy improvements when purchasing new vehicles, the model described here operates at too high a level of aggregation to capture these preferences." (NPRM, p. 43075)

It is true that aggregate statistical analyses are often not able to detect the effects of all important factors. Frequently this is due to the fact that the historical data do not present the analyst with a well-designed experiment with adequate independent variation in the variable of interest. In particular, the average fuel economy of all new light duty vehicles changes gradually and slowly over time, far from an ideal sample design. Nonetheless, the shortcomings of the NPRM's statistical model are not an excuse for neglecting the value of fuel savings to car buyers in the benefit-cost analysis. Omitting fuel economy is inconsistent with both behavioral economic and rational economic theory. It also contradicts the consensus of the empirical literature that consumers do consider fuel economy in their vehicle purchase decisions even if the literature is inconclusive about exactly how much consumers value it.

Finally, the NPRM's ultimate defense of its illogical methodology for predicting the impacts of the proposed rule on vehicle sales is to assume that it must be right.

> "Because the values of changes in fuel economy and other features to potential buyers are not completely understood; (sic) however, the magnitude, and possibly even the direction, of their effect on sales of new vehicles is difficult to anticipate. On balance, it is reasonable to assume that the changes in prices, fuel economy, and other attributes expected to result from their (sic) proposed action to amend and establish fuel economy and GHG emission standards are likely to increase total sales of new cars and light trucks during future model years." (NPRM, p. 43075)

In contrast, we have presented above a coherent explanation for consumers' fuel economy choices based on recent advances in behavioral economics. The well-established principles of behavioral economics explain why, when faced with a simple risky choice to purchase or not purchase a fuel economy technology from a manufacturer, consumers will be loss averse and tend to undervalue expected future fuel savings. On the other hand, the choices consumers are presented with given gradual and across-the-board fuel economy improvements required by fuel economy and greenhouse gas regulations are far more complex and not framed to induce loss aversion. In the context of fuel economy and greenhouse gas regulations, consumers should be expected to fully value the dollars they will save as a result of fuel economy improvements. Nonetheless, even in the context of Expected Utility Theory, the theory and methodology proposed by the NPRM is illogical and self-contradictory.

VIII. Effects of Fuel Economy and Greenhouse Gas Regulations on Vehicle Scrappage

The NPRM's conclusions about the effects of fuel economy and greenhouse gas regulations on vehicle scrappage are based on the assertion that the statistical models of scrappage estimated by the Agencies accurately represent the effects of new vehicle prices and fuel economy improvements on the survival (and scrappage) rates of used vehicles. This quote from the NPRM states that the direction of the impact of fuel economy improvements on used vehicle scrappage rates depends on whether car buyers value the fuel savings more than the increased cost of fuel economy technology.

> "BLS *(Bureau of Labor Statistics, ed.)* assumes that additions to safety and fuel economy equipment are a quality adjustment to a vehicle model, which changes the good and should not be represented as an increase in its price. While this is good for some purposes, it presumes consumers fully value technologies that improve fuel economy. Because it is the purpose to (sic) this study to measure whether this is true, it is important that vehicle prices adjusted to fully value fuel economy improving technologies, which would obscure the ability to measure the preference for more fuel efficient and expensive new vehicles, are not used. (NPRM, p. 43095)

However, the models used to estimate used vehicle scrappage are rendered invalid by overfitting[15], misspecification[16] and multicollinearity[17] due to the inclusion of many, correlated explanatory variables. The models are misspecified because they include no representation of the supply of used cars via new car sales and the effect of supply on used car prices. Used car ownership is most strongly affected by the supply of and demand for used cars. The influence of the price of new cars is indirect and yet new car prices enter the scrappage equations in many different forms but used car prices are absent. The scrappage equation on page 1012 of the PRIA indicates that used car prices are not included in the model and this is confirmed by the coefficient estimates provided in tables 8-10, 8-11, 8-12 and 8-13.

Misspecification is also indicated by the lack of fit of the logistic function to the data for vehicles older than 20 years. The logistic functional form of the model is only an approximation to the true scrappage function: it imposes the implausible assumption that the scrappage curve is symmetrical (see PRIA Figure 8-22) when it is known by NHTSA not to be (NHTSA, 2006). NHTSA acknowledges this lack of fit in the PRIA (p. 1041) and attempts to remedy the problem by splicing an exponential function to the logistic function for vehicles older than 20 years.

> "In the model implementation, an exponential decay function is used beginning at the age when the projected pattern deviates from the observed historical data to ensure that the predicted final fleet share matches the final fleet share observed in the Polk data." (USDOT NHTSA, 2018, p. 1041)

[15] Overfitting is used to describe a model that fits the data on which it was calibrated too well, fitting the noise or errors in the data as well as the underlying relationships between the dependent and explanatory variables. Overfitted models do not predict well outside of the sample on which they have been estimated.

[16] As Winship and Western (2016, p. 628) point out: "Second, social scientists are usually uncertain about the correct model specification. In practice, the true model is virtually never known with certainty."

[17] Multicollinearity describes the situation in which the explanatory variables of a statistical model are highly correlated with each other. Multicollinearity magnifies other shortcomings that almost all statistical models have, such as omitted variables, errors in variables and imperfectly specified functional forms.

While this may help in matching fleet share totals in the Polk data, it does nothing to correct biased coefficient estimates in the scrappage model. Misspecified models with a high degree of multicollinearity are able to fit data well but typically have severely biased coefficient estimates. As a result they are unreliable for making inferences and testing hypotheses about the true effects of individual explanatory variables and are unreliable for predicting beyond the data on which they were estimated (Winship and Western, 2016; Allison, 2012).

The Agencies should have provided customary measures of multicollinearity to allow readers to assess the magnitude of the multicollinearity problem in their models. The most commonly used metric is the Variance Inflation Factor (VIF), defined as the inverse of one minus R^2_i, the R^2 value obtained by regressing one of the explanatory variables (indexed the i^{th} variable) in the model against all the others (Alin, 2010). VIFs are customarily computed for all explanatory variables when multicollinearity is expected.

$$VIF_i = \frac{1}{1 - R_i^2}$$

While it is not possible to calculate exact VIF_is without access to all the data used to estimate the models, even without the data it is easy to demonstrate that the Agencies' scrappage models suffer from severe multicollinearity. The explanatory variables in the passenger car scrappage model, for example, include age, age^2 and age^3, as well as those three variables multiplied individually by five other variables, resulting in eighteen explanatory variables interacted with age or its square or cube. Age, age^2 and age^3 are, by themselves highly correlated (collinear). A regression of age^3 on age and age^2 for ages 0 to 34 produces an R^2 value of 0.995. The VIF for this subset of three variables alone would be 200, twenty times the commonly used threshold of 10. Adding the other variables in the scrappage models to the regression can only increase the value of R^2_i, which means that the true VIF for age^3 is larger than 200.

Overfitted, misspecified models with a high degree of multicollinearity typically have a large number of statistically insignificant coefficient estimates. In the Preferred Car Engineering Scrappage Model (PRIA, Table 8-10, p. 1016) all 34 explanatory variables are included and more than half (18) are statistically insignificant at the customary 0.05 level. In the SUV Preferred model 11 of 29 variables are insignificant but 5 variables in the full model were omitted. In the Truck Preferred model 9 variables are insignificant but 2 have been omitted. As a general rule, the Age, Age^2, Age^3, and the time trend variable and its interaction with the three Age variables are highly statistically significant, as is the variable representing the CARS program. This means that an even greater proportion of the variables representing the effects of vehicle price and fuel costs on scrappage are not statistically significant. In the car model, eight variables with age interactions are estimated to be statistically significant at the 0.05 level while ten are not. The price of a new car and three lagged[18] values of price are included in the regression but also included are the current and lagged price variables multiplied individually by the three age variables, so that there are sixteen variables representing new car price or lagged new car price. Five of those variables are statistically significant but eleven are not. Three lagged values of the dependent variable are also included as explanatory variables. None of the four cost-per-mile variables in the Preferred CAR

[18] The lagged value of a variable is the value from a previous time period. In 2017, for example, the one-year lagged value of gasoline price is the price in 2016, the two-year lag is the 2015 price.

model are statistically significant at the 0.05 level. The SUV and Truck models have fewer insignificant variables but still an unusually large number.

Another symptom of overfitting and multicollinearity is that the coefficients of current and lagged values of variables cancel, or nearly cancel each other. For example, in the Preferred CARS model, the current value of $CPM.Car_{MY}$ has an estimated coefficient of -0.08588378 while its one period lag has a value of +0.08546280. The implication is that if the value of $CPM.Car_{MY}$ changed permanently by 1 unit, the immediate effect would be -0.08588378, but in the next year the effect would diminish to -0.00042098, less than half a percent of the initial effect, for all practical purposes canceling the initial effect. A very similar pattern can be seen in the coefficients for $New.CPM.Car_{CY}$: +0.08029760 is the estimated coefficient for the current value of the variable and -0.10117160 for its value one year later.

Another symptom of overfitting, multicollinearity and misspecification is coefficients that are nonsensical or inexplicable. The coefficients of the car scrappage model exhibit such anomalous effects. The immediate effects of the coefficients will be examined first, followed by their dynamic effects as altered by the three lagged dependent variables included in the car scrappage model. Figure 2 illustrates the effect of a permanent one-unit change in the price of a new vehicle on the dependent variable (the logarithm of the odds in favor of scrappage, ln(s/(1-s)) , where s is the fraction of vehicles scrapped) of the Preferred Car scrappage model as a function of the lag of the new car price variable. Negative values decrease the rate of scrappage and positive values increase it. The effects shown in Figure 2 scale linearly with the change in price, so that a 100 unit change would show the same pattern as a one unit change but with all the bars 100 times higher. The effects of a change in vehicle price tend to alternate in sign from the current value (-) to the one-year lagged value (+) to the two year (-) and three year values (+). The sum of these effects after three years is very small, as shown by the bars labeled "SUM". Such cancelling effects are symptomatic of multicollinearity, overfitting and misspecification. Three bars shaded from lightest to darkest show the effects on 10-, 20- and 30-year old vehicles. Those net effects imply that increased new car prices decrease the scrappage rates of 10-year-old vehicles, have virtually no effect on 20-year-old vehicles and increase the scrappage rates of 30-year-old vehicles. From the perspective of economic theory, none of these patterns make sense. An increase in the prices of new cars, all else equal including no fuel savings benefits, should reduce the scrappage rates of all ages of used vehicles because new and used cars are substitutes. There is no reason why the sign of the effect of a new car price increase should be different for cars of different ages or alternate in sign over the three years following the change.

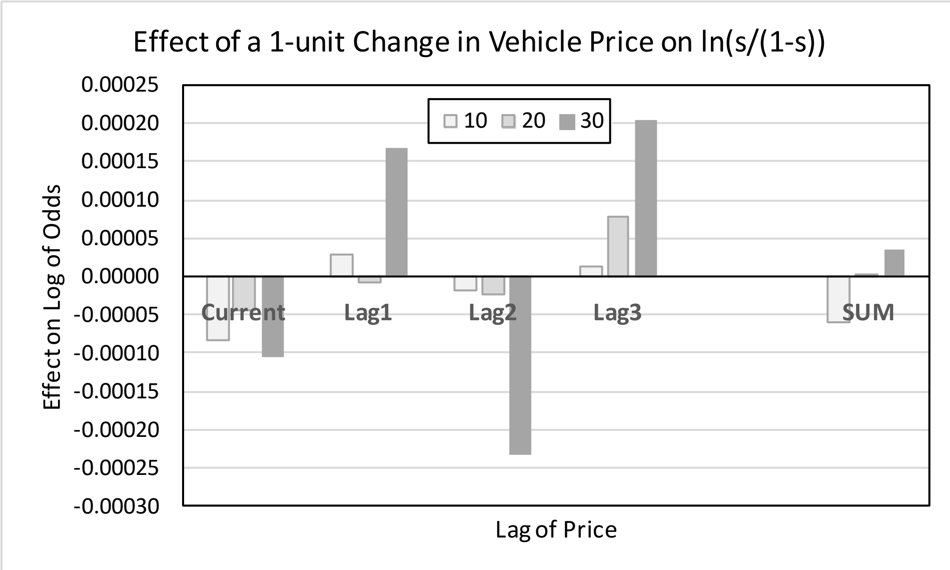


Figure 2. Current Effect of a Permanent 1-unit Change in Vehicle Price on the Log of the Odds in Favor of Scrappage for Vehicles 10, 20 and 30 Years Old in the Preferred Car Engineering Scrappage Model.

The SUM over the lag effects from 0 to 3 years is shown as a function of vehicle age in 5-year increments in Figure 3. For 1-year-old vehicles a new car price increase is predicted to increase scrappage, an anomaly. For 5 to 15-year old vehicles the same price increase decreases scrappage rates, the effect on 20-year-old vehicles is negligible (as in Figure 2), scrappage rates of 25 and 30-year old vehicles are increased but those of 34-year-old vehicles are increased. Once again, there is no explanation for these patterns that is consistent with economic theory.

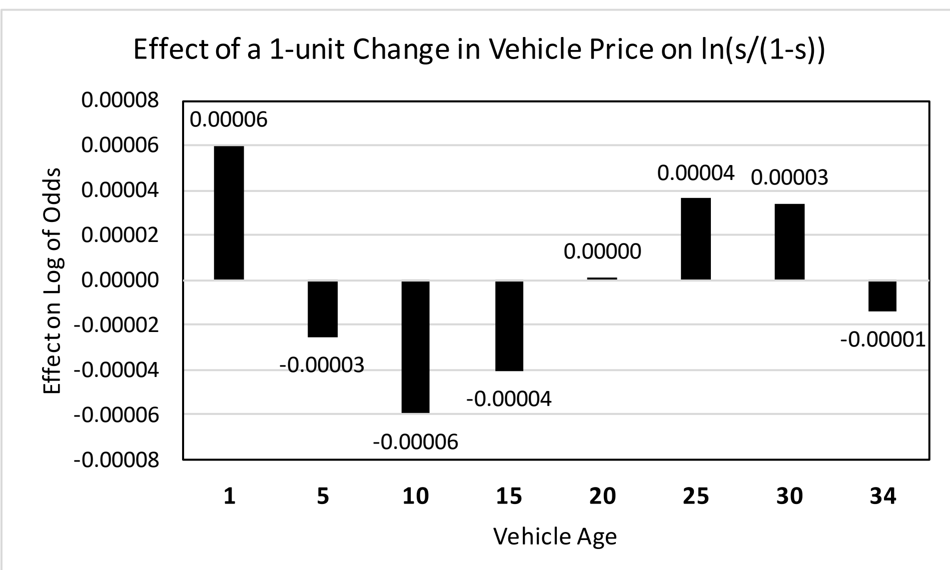


Figure 3. Net Current Effect, Excluding Lagged Effects, of a Permanent 1-unit Change in Vehicle Price on the Log of the Odds in Favor of Scrappage for Vehicles as a Function of Age in the Preferred Car Engineering Scrappage Model.

The three lagged dependent variables in the Preferred Car Scrappage Model cause past price effects to influence the current scrappage rate in addition to the current price effects illustrated in Figures 2 and 3. The lagged effects are taken into account in Figure 4, which shows the dynamic effects of a permanent 1-unit increase in vehicle price over time (periods 0=current to 10 years later) by vehicle age. The changes in scrappage rates over time for 1, 2, and 3-year-old vehicles are anomalous. Initially, the increase in new car price decreased the scrappage rates for 1 to 3-year-old vehicles, as expected. But the effect diminishes over time and after five periods reverses and becomes a positive effect, increasing the scrappage rates of the newest used vehicles, the vehicles which are the closest substitutes for new vehicles. From ages 5 to 15 years the effects are uniformly to decrease scrappage but after twenty years of age the results become once again anomalous. The Agencies replaced the portion of the Preferred Car Scrappage Model beyond twenty years of age with an exponential curve calibrated by a different method, essentially an admission of the model's misspecification. The replacement of part of the Preferred Car Scrappage Model with an alternative functional form does not alter the fact that the coefficients of the Preferred Car Scrappage Model were estimated using all the ages of vehicles. As pointed out above, misspecification in combination with strong multicollinearity produces biased coefficient estimates that cannot be relied on for making inferences or predictions about the magnitudes or directions of the effects of variables in the equation, including fuel cost and new car price.

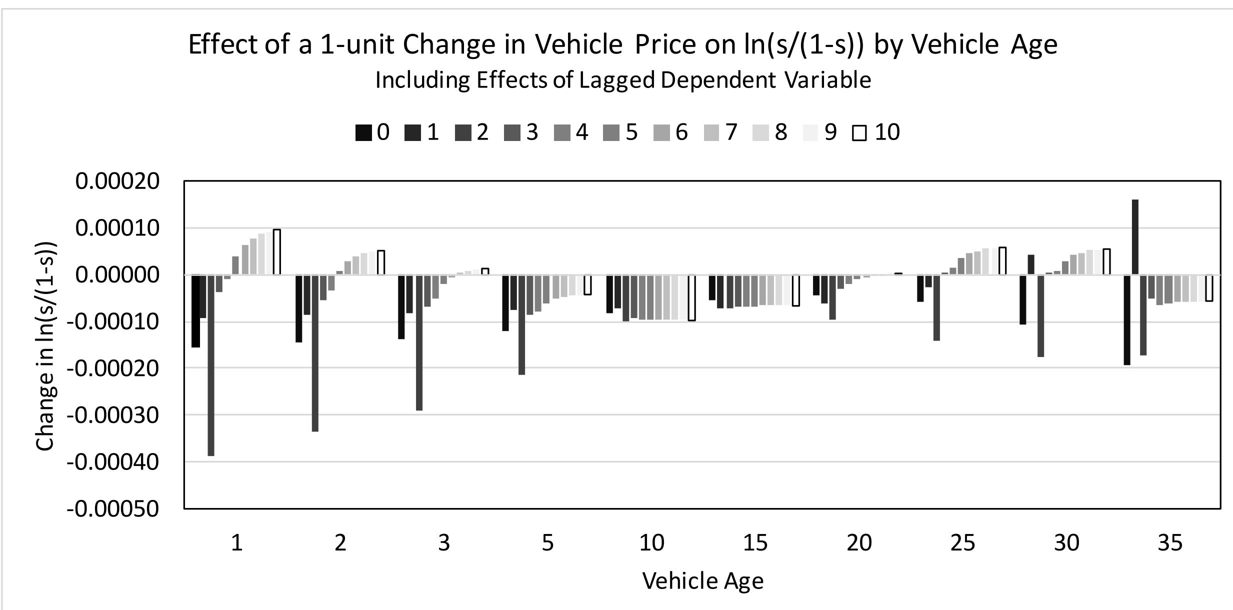


Figure 4. Net Effect of a 1-unit Change in Vehicle Price, Including Lagged Effects, on the Log of the Odds in Favor of Scrappage for Vehicles as a Function of Age in the Preferred Car Engineering Scrappage Model.

The SUV and Truck scrappage models have similar issues. There is no doubt that the models suffer from severe multicollinearity and overfitting, and that inferences regarding the true effects of vehicles prices and fuel costs on scrappage rates are unreliable.[19] Models such as these that suffer from severe multicollinearity, overfitting and misspecification are also not suitable for making predictions.

The NPRM's conclusions about the effects of the existing fuel economy and greenhouse gas regulations on used vehicle prices and scrappage are based on the validity of applying the "Gruenspecht effect" to the existing fuel economy standards (PRIA, p. 999). The Gruenspecht (1982) effect is a slowing of used vehicle scrappage expected to occur when the cost of fuel economy improvements exceeds consumers' willingness to pay for them, leading manufacturers to raise the prices of low fuel economy vehicles and reduce the prices of high fuel economy vehicles in order to achieve partly through sales mix shifts the additional fuel economy improvements required by the standards. This distortion of vehicle pricing makes new vehicles less desirable to consumers, encouraging them to hold onto their used vehicles longer. Thus, the existence or non-existence of the Gruenspecht effect rests on the assumption of rational economic behavior by consumers who base their decisions on EUT. As explained above, modern economic theory and empirical evidence have shown that consumers' decisions can and do systematically deviate from these theories of behavior.

The NPRM cites three key studies it claims demonstrate the validity of the Gruenspecht effect in reality. In fact, the studies do no such thing. All three studies actually assume the Gruenspecht effect by constraining their models and data to conform to the theory of rational economic behavior and expected utility theory.

The existence of a Gruenspecht effect depends on whether or not standards can be met with technology consumers are willing to pay for. Faced with fuel economy and greenhouse gas regulations, manufacturers adopt technologies that increase fuel economy but also generally add to the cost of manufacturing vehicles. As noted above, manufacturers will resort to differential pricing of vehicles to induce sales shifts toward more fuel efficient vehicles only when they cannot meet the standards with cost-effective technology for which consumers are willing to pay (e.g., Liu et al., 2014), in other words, when the standards become a binding constraint. As long as cost-effective technology is available, the increase in vehicle prices is determined by the cost of the fuel economy technologies needed to meet the standards. Up to the point where the cost of fuel economy technology just exceeds its fuel savings (i.e., standards become a binding constraint), consumers' willingness to pay for fuel economy improvements exceeds their cost. Up to that point, consumers will prefer the higher fuel economy vehicles required by the standards. Because consumers prefer the new, more fuel efficient vehicles, sales of new vehicles increase. At the same time, because the new vehicles offer greater value the prices of used vehicles will decrease and rates of retirement or scrappage will increase. Thus, unless fuel economy standards are a binding constraint on manufacturers, the Gruenspecht effect will not occur. Indeed, the result will be the opposite: increased sales of new vehicles and an increased rate of turnover of the used vehicle stock.

The three key papers on the Gruenspecht effect cited by the NPRM do not prove that fuel economy standards will cause a Gruenspecht effect, rather the papers assume that they will. In their paper on the

[19] Winship and Western (2016, p. 629) conclude: "The critical insight is that multicollinearity can enormously magnify the effects of model misspecification." And on page 635: "In sum, multicollinearity can substantially affect the robustness of OLS estimates to model misspecification. Small errors in model misspecification can lead to large biases in parameter estimates."

effects of CAFE standards on vehicle scrappage, Jacobsen and van Benthem (2015) do not analyze the current footprint-based standards but rather the previous form of the CAFE standards.

> "We base the model on the Corporate Average Fuel Economy (CAFE) standards in the United States, incorporating separate standards for car and light truck fleets though not the recent "footprint-based" innovation." (Jacobsen and van Benthem, 2015, p. 1328)

This is important because the footprint standard reduces the incentive to price vehicles to increase fleetwide average fuel economy because it adjusts the standard a manufacturer must meet according to the sizes of the vehicles it produces.

The paper does not provide the fuel economy cost functions used in the analysis but instead states that their assumptions about fuel economy cost functions come from Goulder, et al. (2012).

> "For all other parameters (e.g., demand elasticities, parameters of the fuel economy cost functions), we follow Goulder, Jacobsen and van Benthem (2012)." (Jacobsen and van Benthem, 2015, p. 1330)

Goulder et al. (2012, p. 197) states that the slopes of the cost functions (the marginal costs of fuel economy improvement) used are taken from Jacobsen (2007), an unpublished working paper later published as a journal article (Jacobsen, 2013) with the same title.

> "The slope of the aggregate cost function (or the optimal combination of the *c* and *h* functions)[20] around the profit-maximizing point depends on two factors: the demand for fuel economy from consumers and the shadow value[21] of fuel economy due to pre-existing CAFE standards. For the first of these we assume forward-looking consumers, such that willingness to pay for a marginal improvement in fuel economy reflects the discounted stream of savings on gasoline. The shadow value due to CAFE is taken from Jacobsen [15] and combined with consumer willingness to pay to determine the baseline slope of the quadratic cost function.[26]"

Footnote 26 states:

> "The value of an extra mile per gallon to the consumer ranges from $150 to $530 across models, while the pre-existing CAFE standards add between $50 and $600 in shadow value in the central case."

By assuming that manufacturers have already supplied all the technology that would be paid for by its fuel savings over the life of a vehicle, the authors assure that any additional technology added to improve fuel economy will cost more than the full value of its fuel savings. This is equivalent to assuming that in the absence of regulations consumers will pay for the full lifetime discounted present value of fuel savings and that in the absence of fuel economy and greenhouse gas regulations the market would provide exactly that level of fuel economy. Then, because they assume this must be true, it follows that

[20] The *c* functions are marginal production cost functions and represent the cost of using technology to increase fuel economy. The *h* functions are intended to represent the effect of investment in research and development on the cost of fuel saving technologies.

[21] The shadow value of a regulatory constraint such as the CAFE standards is the dollar cost of tightening the constraint by one unit (e.g., one MPG). If the regulation is not a binding constraint on manufacturers the shadow cost is zero.

any further fuel economy improvements cannot be cost effective and therefore must be a binding constraint on manufacturers, and will result in differential pricing of vehicles to induce sales mix shifts.

The main analysis of CAFE standards presented in Jacobsen (2013) assumes that manufacturers use only differential pricing and *no technology* to meet CAFE standards, an extreme and demonstrably false assumption. As a side case, Jacobsen added an analysis of the "possibility for endogenous technology improvements in fuel efficiency" (p. 176) using a cost function from NRC (2002). However, the NRC cost function was used in a way that contradicted its premises. In footnote 54 Jacobsen states,

> "These curves contain a number of negative net cost improvements (worthwhile even without a CAFE standard) that must be reconciled with the observed technology choices in the baseline data. To do this, I assume that the observed fuel economies are rational for producers in that the marginal technology cost in the baseline equals the value of fuel saved plus the shadow cost of CAFE."

In other words, Jacobsen (2013) assumes that the technologies identified by the NRC committee could not possibly be available to improve fuel economy because consumers and producers are perfectly rational economic agents and therefore the market would already have adopted them. This assumption allows him to move up the quadratic technology cost curve (see figures 1a and 1b) to points with higher marginal costs (steeper slopes), based on the assumption that technologies that would have paid for themselves on a financial basis alone must have already been adopted and therefore could not be available. This disregards low-cost technologies the NRC (2002) committee specifically and intentionally identified as available for use to improve fuel economy, thereby contradicting the method and data used by the NRC committee to construct the cost functions and greatly increasing the marginal cost of fuel economy. By insuring that the marginal cost of further fuel economy improvements is greater than consumers' willingness to pay for them, Jacobsen's method guarantees that the fuel economy regulations will be a binding constraint on manufacturers. This, in turn, insures that manufacturers will use differential pricing to increase fuel economy and, because he has moved to the steeper portions of the curve, it insures that the shadow prices will be relatively high.

This is clearly an incorrect use of the NRC curves because it overrides the committee's painstaking expert analysis with the sweeping assumption that the market for fuel economy must be efficient. The NRC (2002) committee (comprised of experts in automotive engineering, economics and market research among other professions) constructed the cost functions using existing technologies proven to increase the fuel economy of 1999 model year vehicles, taking into account the extent to which the technologies had already been adopted in new vehicles sold in 1999. Historical data on technology adoption proves that the key technologies included in the NRC (2002) cost curves were not adopted until after 1999. The engine technologies on which the NRC (2002) cost functions were based include multi-valve engines (e.g., 4 vs. 2 valves), variable valve timing (VVT) and VVT with lift control, gasoline direct injection (GDI), turbo-charging with engine downsizing (Turbo), engine off at idle (Stop/Start) and cylinder deactivation at low engine loads. Of these, only multi-valve engines had attained an important market share in the U.S. in 1999 (Figure 2) (USEPA, 2017), a fact that was taken into account in constructing the committee's cost functions. The other technologies were all but entirely adopted after the 1999 model year. The remaining engine technologies in the NRC study (friction reduction and reduced parasitic loads) are difficult to attribute to a specific, identifiable technology. The ratio of horsepower to cubic inch displacement (HP/CID) is a good indicator of overall engine efficiency (USEPA, 2017).[22] From 1985 to 2017 the average HP/CID ratio increased by 125% with more than half of the increase occurring after the 1999 model year (Figure 2).

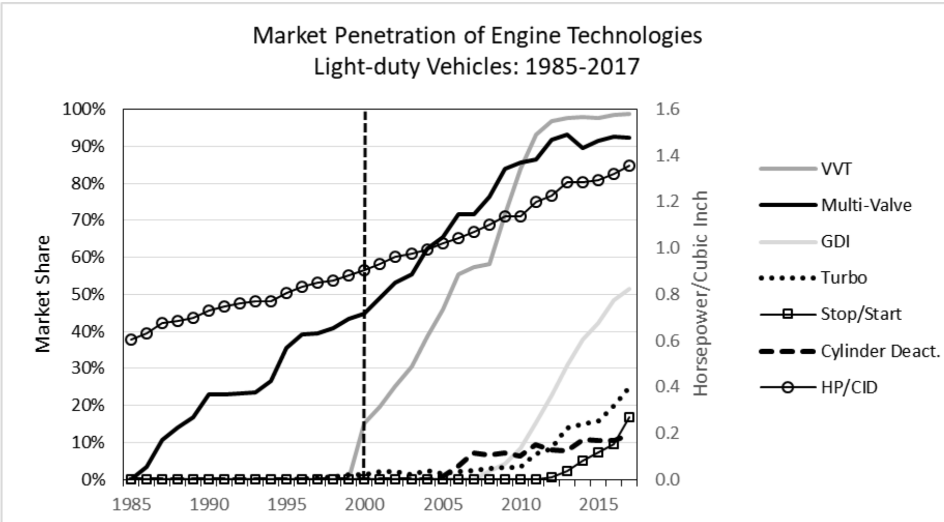


Figure 2. Market Penetration of Engine Technologies in U.S. Light-duty Vehicles: 1985-2017 (USEPA, 2017, table 5.3.1)

The transmission technologies considered by the NRC (2002) committee included increasing the number of gears from 4 to 5 or 6 and continuously variable transmissions (CVT). Again, only 5-speed transmissions had a non-trivial market share in 1999. The more advanced transmissions were adopted afterwards (Figure 3).

Although the NRC (2002) cost functions apply to a 1999 vehicle, it is incorrect to assume that technology to improve fuel economy would be exhausted by 2010 or 2015. As the cost curves in Figures 1a and 1b show, new fuel economy technologies are constantly being developed. In fact, the cost functions derived from NRC (2015) show a greater potential to increase fuel economy at lower cost than the NRC (2002) cost functions. Over the 2002 to 2015 period, technologies with the potential to cost-effectively improve fuel economy were being invented more rapidly than they were being adopted.

[22] The efficiency of a heat engine is measured by the ratio of work done to heat provided. At any given engine speed horsepower is proportional to work done and heat provided is proportional to displacement.

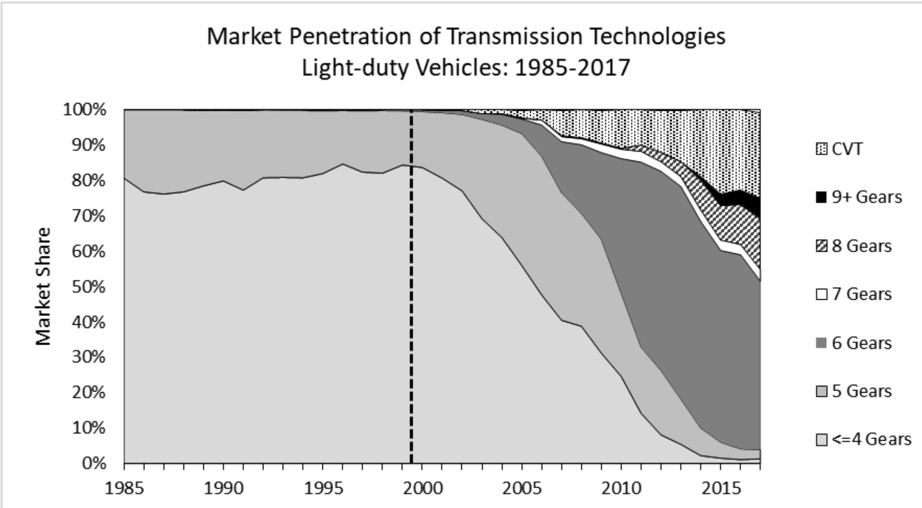


Figure 3. Market Penetration of Transmission Technologies in Light-duty Vehicles: 1985-2017 (USEPA, 2017, table 5.4.1).

Among the sensitivity analyses of their model, Jacobsen and van Benthem (2015) include re-calibrating their fuel economy cost function using the NHTSA Volpe Model's cost function (NHTSA, 2012). Because they do not mention or describe any change to their calibration method, it must be assumed to be the same as used in the main part of their study, over-riding the expert assessment of the costs of improving fuel economy. Thus, while they note that the Volpe Model cost functions have smaller slopes (lower marginal costs) than the NRC (2002) cost function (as do the NRC, 2015 cost functions) they again conclude that manufacturers will use vehicle pricing to shift sales toward higher fuel economy vehicles. Because their analysis does not incorporate the footprint standards, manufacturers also use pricing to increase sales of smaller vehicles, a result inconsistent with the footprint standards.

Because the papers cited by the NPRM assume rather than prove that fuel economy standards cause pricing to induce sales mix shifts, they do not constitute empirical evidence of the Gruenspecht effect for fuel economy and greenhouse gas regulations. The systematic misinterpretation of technology cost functions by Goulder et al. (2012), Jacobsen (2013) and Jacobsen and van Benthem (2015) leads them to erroneously conclude that fuel economy standards lead to increased prices for new cars that exceed the value of the fuel savings they will provide. This, in turn, would increase the prices of used cars and reduce rates of used vehicle scrappage. In fact, their conclusions about the Gruenspecht effect are a direct consequence of their decision to overrule the expert evidence provided by the NRC cost function. They have assumed the existence of the Gruenspecht effect for fuel economy and greenhouse gas regulations, not produced evidence of it.

IX. Conclusions

The NPRM reaches incorrect conclusions about the benefits and costs of the existing fuel economy and greenhouse gas regulations because:

1. It does not understand how consumers evaluate fuel economy improvements in their vehicle purchase decisions. Recent advances in behavioral economics provide a coherent explanation which the NPRM has not taken into account.

2. The NPRM's confusion about this fundamental issue is reflected in the incoherent and self-contradictory methodology it uses to evaluate the impacts of fuel economy and greenhouse gas regulations on vehicle sales and the turnover of the stock of used vehicles.
3. Contrary to the NPRM's own review of the econometric literature, from which it concludes that consumers value fuel economy at somewhere between half and all of the discounted expected value of future fuel savings, the NPRM's model for predicting future vehicles sales includes the incremental cost of fuel economy improvements but not the value of fuel savings. The NPRM's methodology not only contradicts economic theory but it also contradicts its own assessment of the econometric literature.
4. The NPRM's used vehicle scrappage model is misspecified and includes as explanatory variables numerous highly correlated variables, such as vehicle age, age^2, and age^3, lagged values of independent and dependent variables and their interactions with age, age^2, and age^3. Misspecification and multicollinearity of this nature produces strongly biased coefficient estimates and poor ability to predict outside of the sample data on which the model was estimated. As a consequence, inferences about the effects of price and fuel cost on scrappage are invalid, and the model cannot be relied on to predict the impacts of changes in new vehicle prices and fuel costs on vehicle scrappage.

The deficiencies in the Agencies' benefit-cost analysis described in this report are serious and invalidate the conclusions about vehicle sales and scrappage reached by the NPRM.

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Summary of "Impacts of fuel economy improvements on the distribution of income in the U.S."
(Greene and Welch, 2018).

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October 12, 2018

Vehicle manufacturers will typically meet fuel economy and greenhouse gas regulations by adopting technologies that reduce fuel consumption and emissions but increase the cost of manufacturing vehicles. How increased fuel economy affects different income groups is of interest. The study by Greene and Welch estimates the impacts of fuel economy improvements on US households' income. Households are divided into five income groups, each containing 20% of US households. Only savings on fuel and increased vehicle costs due fuel economy improvements to passenger cars and light trucks are considered. The study covers the period from 1980 to 2015 but considers fuel economy improvements to all model years of vehicles in use during that time.

The study addresses this question by using the directly measured estimates of fuel savings and authoritative estimates of price increases due to fuel economy improvements. Households' fuel expenditures were obtained from the Consumer Expenditures Survey, a comprehensive, scientifically designed survey of U.S. households' expenditures. The Survey is used to calculate the Consumer Price Index, among other purposes. Fuel savings were calculated by subtracting what households would have spent on fuel had vehicle fuel economy not increased over the level in 1975 from what they actually spent. In making this calculation, the "rebound effect", the tendency for vehicle travel to increase when improved fuel economy reduces the fuel cost per mile of travel, was taken into account.

Estimates of the cost of increasing fuel economy come primarily from four studies by the National Research Council (NRC). The NRC committees that produced the estimates are comprised of balanced panels of experts in automotive engineering, economics, motor vehicle markets and other relevant disciplines. Their conclusions are thoroughly peer-reviewed. The NRC studies provide cost estimates for new car fuel economy improvements from 1990 to 2025. For earlier model years, the study relies on estimates published in the peer-reviewed literature. According to the NRC cost estimates, fuel economy improvements to new vehicles were cost-effective in every year, assuming that consumers took account of the present value of fuel savings over the life of the vehicles.

Given the cost-effectiveness of fuel economy technologies available in all years, one would expect the fuel economy improvements to produce net savings, on average, for US households. Because most new vehicles are bought by upper income households while lower income households tend to purchase more used vehicles, the impacts on households depends on how fuel economy changes as vehicles age and how the costs of fuel economy improvements to new cars are passed on to used car buyers. In fact, the fuel economy of a vehicle changes very little over its lifetime because it is primarily determined by the vehicle's weight, engine size and the technology incorporated in it. Vehicle prices, on the other hand, depreciate relatively rapidly. Typically, vehicles lose 10% or more of their value as soon as they are driven off a car dealer's lot and lose roughly another 10% per year as they get older. Greene and Welch's econometric analysis of the CES data on households' vehicle purchases found similar rates of depreciation. Because of this, purchasers of used vehicles are able to obtain essentially the same reduction in fuel use per mile as new vehicle purchasers but at a much lower cost.

Greene and Welch found that all income groups received net savings due to fuel economy improvements over the period 1980 to 2014. In terms of total dollar savings the highest income groups saved the most, averaging $16,000 in savings, while the lowest income 20% of households saved over $6,000 (2015 $). This is because higher income households own more vehicles and drive them farther. As a percent of income, however, the highest income households saved the least, 0.4%, and the lowest income households the most, 1.5%. The overall effect was to reduce the disparity in the distribution of household income. Reasonable changes in assumptions did not alter these findings.

Using official government estimates of future vehicle sales, fuel economies and fuel prices, combined with NRC estimates of the costs of future fuel economy improvements, Greene and Welch estimated the likely impacts of future fuel economy improvements over the period 2015 to 2050. The government projections assumed that the existing fuel economy and greenhouse gas emissions standards through 2025 would be met but assumed no increase in the standards after 2025. The estimated impacts by income group were essentially the same as those in the past. All income groups received net savings, with total savings by all households amounting to $170 billion per year in 2025 and cumulative savings over the 2015-2050 period totaled $3.5 trillion. Again, the distribution as a percent of income was favorable to the lower income groups, averaging 2.2% of income for the lowest income 20% and 0.5% for the highest income 20%.

Greene, D.L. and J.G. Welch, 2018. “Impacts of fuel economy improvements on the distribution of income in the U.S.”. *Energy Policy*. 122, 528-541.