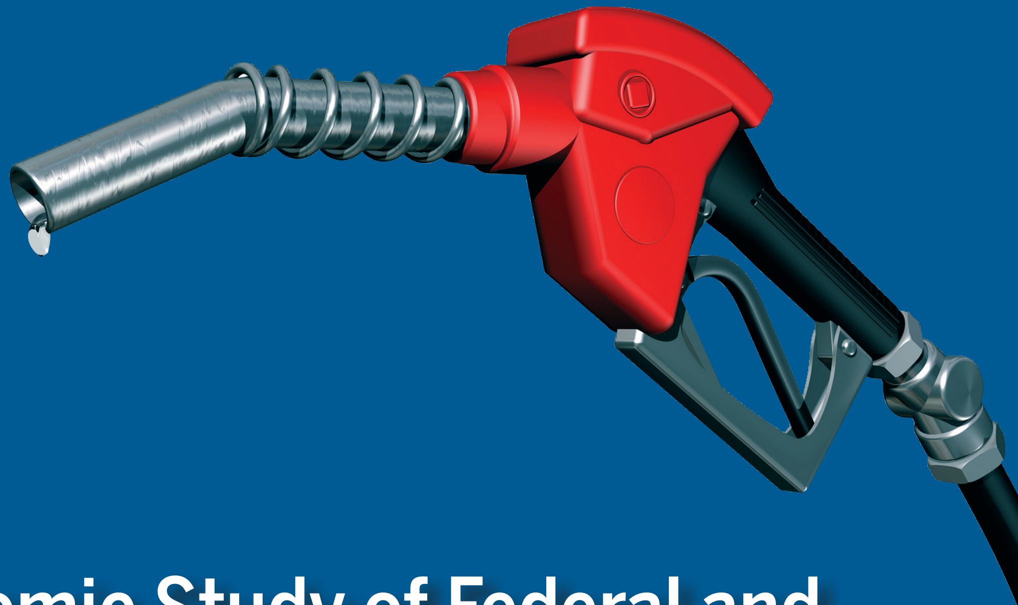

A Macroeconomic Study of Federal and State Automotive Regulations

with Recommendations for Analysts, Regulators, and Legislators

Sanya Carley, Denvil Duncan, John D. Graham, Saba Siddiki, and Nikolaos Zirogiannis

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REPORT INFORMATION AND ACKNOWLEDGEMENTS

This is the final report of an 18-month study conducted under a grant agreement between Indiana University and the Alliance of Automobile Manufacturers. It builds on our preliminary report, *Rethinking Auto Fuel Economy Policy: Technical and Policy Suggestions for the 2016-2017 Midterm Reviews*. School of Public and Environmental Affairs, Indiana University. February, 2016 (https://spea.indiana.edu/doc/research/working-groups/fuel-economy-policy-022016.pdf). The authors are fully and independently responsible for the design, execution, and findings of the study. The findings and views expressed in the report are those of the authors and do not necessarily represent the views of the Alliance of Automobile Manufacturers or Indiana University. The authors are especially grateful to have received guidance and constructive criticism from the project's Peer Review Advisory Board and consultants Alan Jenn of the University of California at Davis, and Wally Wade, a former chief engineer and technical fellow in Powertrain Systems Technology and Processes at Ford Motor Company, who is also a member of the National Academy of Engineering. We also appreciate helpful information from staff at several federal agencies (DOE, EPA, DOT, EIA, and OMB) and a variety of manufacturers, suppliers, and related associations. The February 2016 Preliminary Report, which covered the regulatory aspects, also benefited from written peer reviews supplied by the following experts across the U.S.: Hunt Allcott (New York University), John DeCicco (University of Michigan), Salim Furth (The Heritage Foundation), Ted Gayer (Brookings Institution), Rachel Krause (University of Kansas), Don Mackenzie (University of Washington), and one anonymous regulatory expert. Revisions in response to those peer reviews are reflected in this final report. The findings and views expressed in the report do not necessarily represent the views of any of these peer reviewers. We also acknowledge helpful informal comments from John German and Tom Walton, and from participants of the 2016 annual conference for the United States Association of Energy Economics, the 2016 annual conference for the International Association of Energy Economics, the 2016 University of South Carolina International Journal of Law and Business symposium, the 2016 Austin Energy Workshop, and the 2016 annual conference for the Association of Public Policy Analysis and Management. Rebecca Snedegar provided excellent administrative assistance throughout the project as well as leads on important studies and developments. Dan Esposito, Emily Hall, Alyssa Julian, and David Michael provided helpful research assistance. Comments on the report are welcome and can be submitted to bsnedega@indiana.edu.

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EXECUTIVE SUMMARY

This study examines how the U.S. economy is likely to be impacted by the combined effects of three automotive regulatory programs that were adopted in 2012: the U.S. Department of Transportation's corporate average fuel economy (CAFE) standards for model years 2017-2025; the Environmental Protection Agency's greenhouse gas (GHG) emissions standards for model years 2017-2025; and the California Air Resources Board's Zero-Emission Vehicle (ZEV) requirements for 2018-2025.

A combined analysis of these three regulatory programs and their impacts is provided for several reasons: all three programs share similar policy objectives (e.g., reducing the greenhouse gases that contribute to climate change); cover products—cars and light trucks—produced by the same industry; become increasingly stringent in the same time frame; have interdependent practical consequences (e.g., it is more difficult for automakers and dealers to commercialize plug-in electric vehicles under the California ZEV program when the federal programs are making gasoline-powered vehicles more fuel-efficient than they would otherwise be); and can be modified—through legislative and/or administrative action—by the U.S. federal government.

2012 vs. 2016 Perspectives

A distinctive feature of this study is that the programs are analyzed from two perspectives. The "2012 perspective" uses inputs reflecting evidence that was available from 2009-2012, when the 2012 programs were being developed. The "2016 perspective" uses inputs that reflect new information that has become available since 2012 on the California ZEV program, technology costs, fuel-saving effectiveness, fuel prices, vehicle miles traveled, vehicle resale values, and consumer behavior. Thus, we seek to determine whether macroeconomic impacts looked differently in 2012 than they do today.

Compared to the 2012 inputs, the 2016 inputs reflect (1) a larger vehicle price premium due to the suite of federal and California regulations, which will grow in stringency from model years 2017-2025; (2) a large reduction in the federal government's official forecast for average gasoline prices in 2025, down from $3.84 per gallon to $2.74 per gallon; (3) new evidence on how vehicle purchasers perceive and value fuel economy, both during their ownership period and when they resell their vehicle; (4) new evidence on how many miles Americans travel each year over the long lifetime (up to 30 years) of a vehicle; and (5) new evidence and forecasts showing a rapid decline in the price of lithium-ion battery packs and the cost of producing plug-in electric vehicles (PEVs). The modeling explores how the new inputs, individually and in combination, change the macroeconomic forecasts of the impacts of the regulations.

Choice of Economic Indicators

Three macroeconomic indicators are considered: employment levels, gross domestic product (GDP), and real disposable income at the household level. Each of the three indicators are standard economic performance measures watched closely by policy makers, Wall Street and other financial analysts, investors, and stakeholders in the industry such as labor union leaders, car dealers, original equipment manufacturers, and parts suppliers.

We also undertake separate analyses of the impact of the regulations on the volume of new vehicle sales, since new vehicle sales are a key sectoral indicator as well as a closely-watched indicator of the overall health of the economy. In addition, the volume of new vehicle sales influences how fast the environmental objectives of the regulations can be accomplished and influences the societal costs and benefits of those regulations.

Causal Pathways for Economic Impacts

We consider three causal pathways for how the regulatory standards could impact the U.S. economy: (1) by raising the average cost of producing new vehicles, and passing those costs on to the average prices of new vehicles which will be felt by consumers; (2) by stimulating the automotive supply chain as original-equipment manufacturers and suppliers innovate, hire additional workers, and produce new technologies such as turbocharged engines, new transmissions, lightweight materials, conventional hybrid engines, advanced diesel engines, and plug-in electric vehicles; and (3) by reducing gasoline consumption with positive spending reallocations for households, businesses, and governments, and negative effects in the U.S. petroleum sector, including the supply chains that are related to oil and gasoline production. We show results for each of the causal pathways individually as well as the combined impact of the three pathways.

Modeling Platform

The modeling platform chosen for the analysis is REMI PI 2.0.2, a well-known and versatile macroeconomic model that combines information on the U.S. economy from four general sources: input-output matrices, general equilibrium tools, econometrics, and economic geography. REMI is particularly appropriate for regulatory application because it accounts for impacts in different subsectors of the economy (e.g., automotive and petroleum) while also simulating the ripple effects through long supply chains and the indirect spending impacts on households and communities that depend on those supply chains.

To provide some capacity for regional analysis, we selected a version of REMI that breaks down the U.S. economy into nine Census regions, with each of the 50 states represented in one of the nine regions. Thus, the study simulates macroeconomic results for the U.S. economy as a whole as well as for each of its nine Census regions.

Basic Findings

Our basic findings from the REMI modeling are that (1) the vehicle price effects, which increase as standards become more stringent, cause significant losses of employment, GDP, and disposable income through a decline in new vehicle sales and higher vehicle prices for consumers, which in turn curbs spending on other goods and services; (2) the supply chain innovations induced by the regulations offset, on a national basis, at least half of the adverse effects of higher prices as additional investments in fuel-saving technology boost employment, output, and disposable income; and (3) the savings in gasoline expenditures trigger reallocations in spending that have a much more positive impact on the economy than the negative impacts on the U.S. petroleum sector and its supply chains.

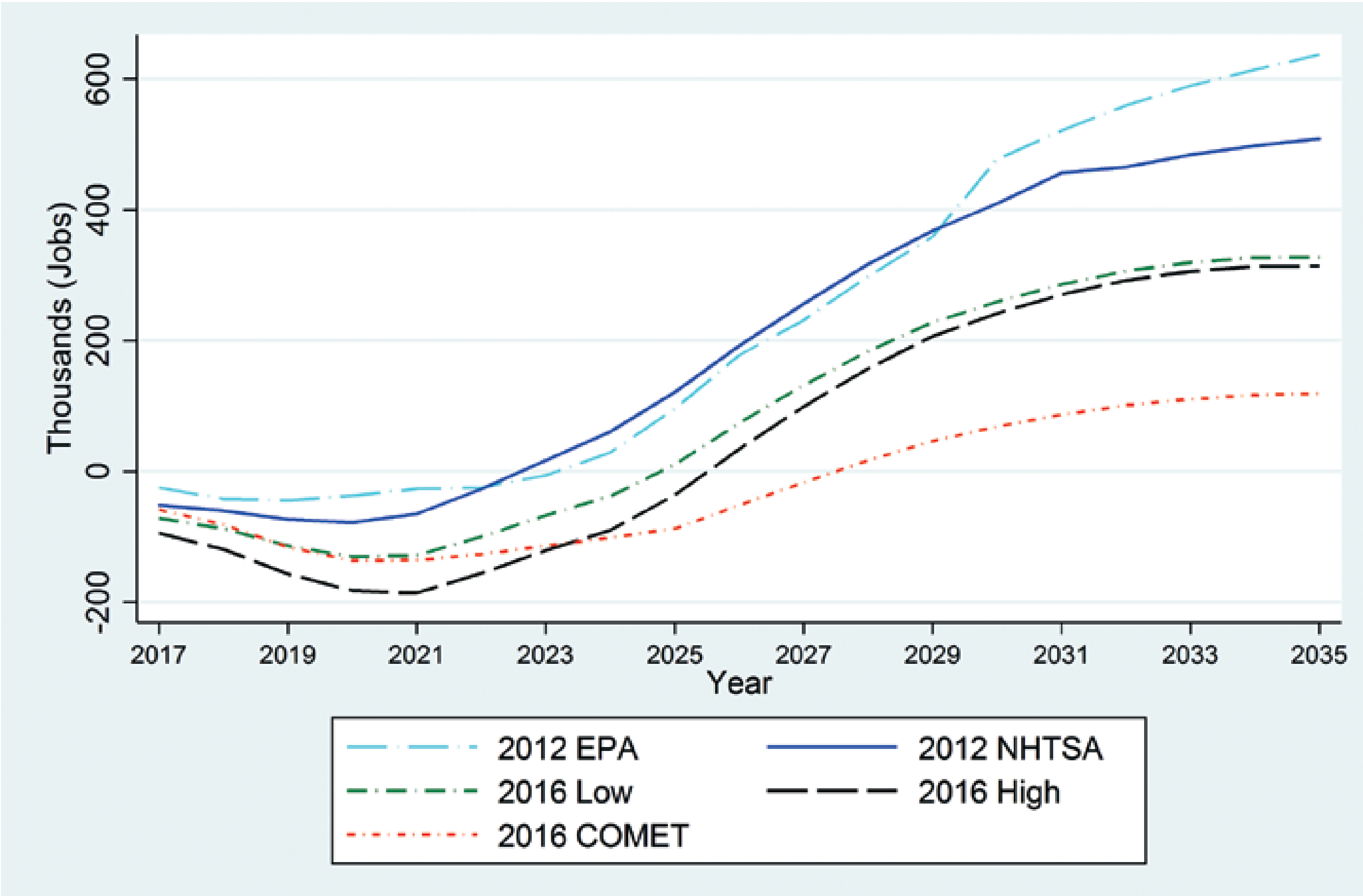
When the three causal pathways are modeled together, the overall annual impact of the regulatory programs on the national economy is negative in the near-term but positive in the long-term, a pattern that is consistent with theoretical expectations. The annual impact turns from negative to positive as early as 2022 and as late as 2035, depending on the inputs used in modeling. These trends are illustrated in Figure ES.1 below. In general, the positive effects on the economy are ultimately larger in magnitude than the negative impacts, primarily because the fuel savings are quite large relative to technology costs.

The national findings from the REMI modeling are consistent throughout the nine Census regions with two important exceptions: the oil-producing West South Central region of the U.S. (Arkansas, Louisiana, Oklahoma, and Texas) experiences net negative effects throughout the study period, and the East North Central region of the U.S. (Illinois, Indiana, Michigan, Ohio, and Wisconsin), where much of the automotive supply chain is concentrated, takes longer than the national average to experience net positive economic effects from the regulations.

When the 2012 inputs are replaced with the 2016 inputs, the pattern of macroeconomic impacts tend to be somewhat worse, though still positive in the long run. With the 2016 inputs, it generally takes longer for the economic impacts to become positive since most, though not all, of the new 2016 information is unfavorable to the 2012 regulations (e.g., lower fuel prices, higher cost estimates for compliant technology packages, and additional costs for the California ZEV program).

Results may also be viewed from a cumulative perspective, where each year's positive or negative effects are combined for a specified time period. In the long run, cumulative effects are ultimately positive but will take

Figure ES.1. Employment Estimates Measured as the Difference between Baseline and Federal and State Standards in Thousands of Job-Years, 2017-2035



Note: This graph includes five different scenarios. The first, "2012 EPA," uses data published in the Environmental Protection Agency's 2012 Regulatory Impact Assessment (RIA) and does not include the ZEV standard. The second, "2012 NHTSA," similarly uses data from the National Highway Traffic and Safety Administration's 2012 RIA and does not include the ZEV standard. These two scenarios represent the "2012 perspective," whereas the remaining three represent the "2016 perspective." The "2016 Low" and "2016 High" scenarios are based on NHTSA "2016 perspective" data, including fuel price adjustments, NRC (2015a) technology cost adjustments (one of a smaller magnitude and the other of a larger magnitude), and does include the ZEV standard. Finally, the "2016 COMET" is based on technology costs produced through the Cost Optimization Modeling for Efficiency Technologies (COMET) model, using EPA data, as well as fuel price adjustments. All five scenarios include three causal mechanisms to capture the impacts of federal and state regulations: (1) a price premium; (2) a corresponding investment in supply chain innovation; and 3) savings from reduced gasoline expenditures.

many years to become so because the negative annual effects are concentrated in the near term. Using the three 2016 datasets, we found that the cumulative effects on U.S. GDP from 2017 to 2025 were negative but the 2025 stopping point omits consideration of the large fuel-savings impacts of the vehicles produced in 2025. When we extend the time horizon to 2035, two of the 2016 datasets show positive impacts on GDP while one 2016 dataset shows negative cumulative impacts on GDP. Once again, the results of the cumulative modeling using 2016 inputs are worse for the U.S. economy than the results based on the 2012 inputs.

Total Consumer Cost of Ownership Model

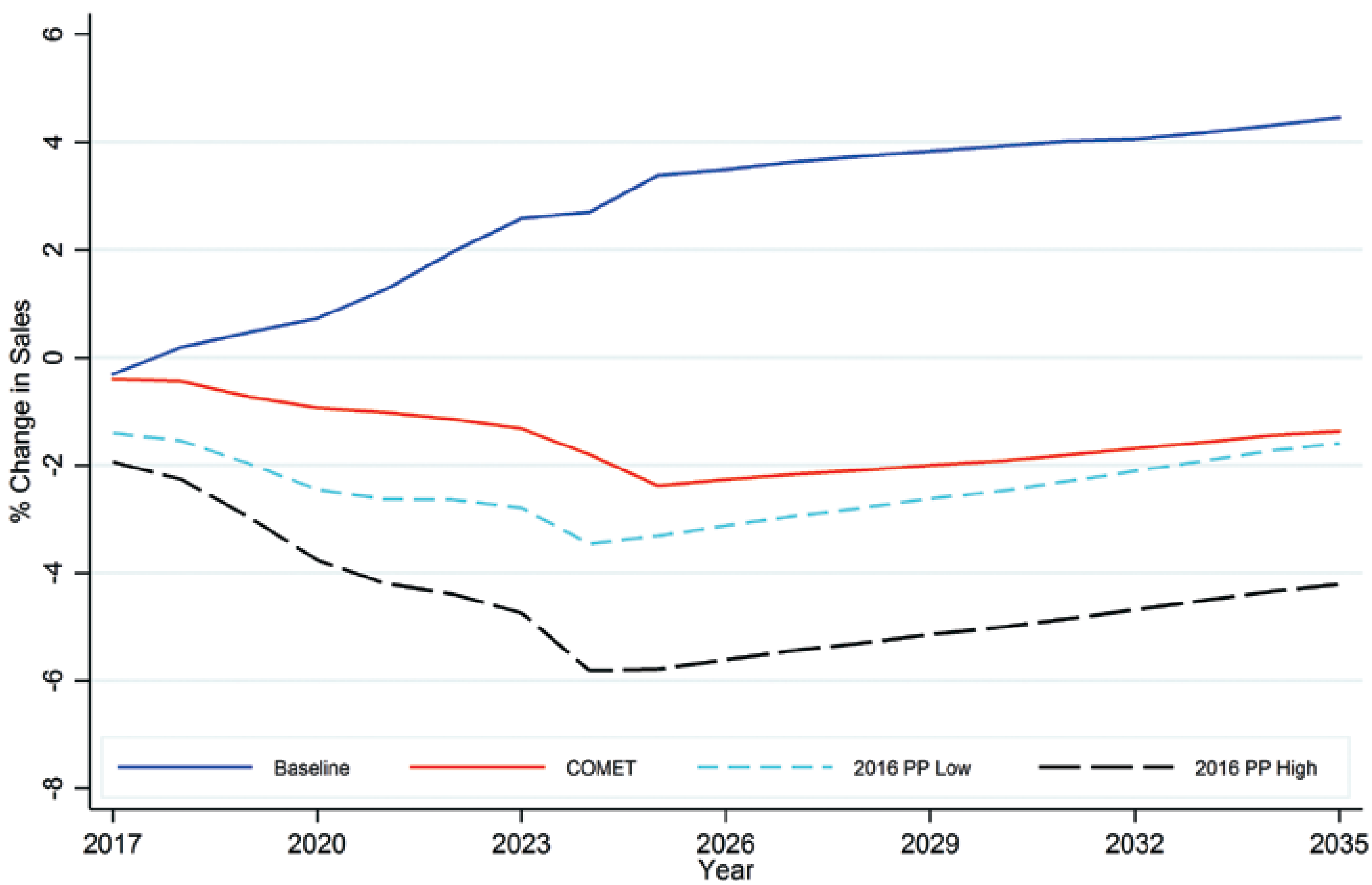
The REMI model is limited in its ability to consider recent evidence of consumer valuation of enhanced fuel economy. Thus, we also performed total-cost-of-ownership (TCO) modeling to simulate the impacts of the regulatory programs on new vehicle sales. The advantage of the TCO approach is that it considers recent evidence that consumers value fuel savings from new technology when they purchase a new vehicle.

Using a TCO approach similar to that used by the U.S. Department of Transportation over the last fifteen years, we estimate the combined impact on new vehicle sales for the 2012 perspective, when only the two federal regulatory programs are considered. For the 2016 perspective, we add the California ZEV program and consider new information on technology costs, fuel-saving effectiveness, vehicle miles of travel, consumer valuation of fuel savings, resale values, and fuel-price expectations of consumers. Separate estimates of vehicle-sales impacts are provided for passenger cars and light trucks.

Findings: Impacts on New Vehicle Sales

In general, the pattern of results indicates positive effects on new vehicle sales from the 2012 perspective but negative effects on new vehicle sales from the 2016 perspective. Figure ES.2 presents the TCO results on new vehicle sales for alternative price premiums. The results of the TCO modeling are somewhat sensitive to assumptions about how strongly consumers value fuel savings and thus, in the report, we present results for a wide range of assumptions about consumer valuation of fuel savings.

Figure ES.2. Percentage Change in Car Sales



Note: Percentage change in vehicle sales due to regulatory programs based on four perspectives. Baseline is drawn from NHTSA's 2012 data, and represents the 2012 perspective. The remaining lines represent the alternative 2016 perspectives. Of the three 2016 perspectives, COMET alone accounts for the interdependence between CAFE and ZEV. Consumer valuation of fuel savings differs between the 2012 and 2016 perspectives: baseline assumes that consumers value five years' worth of fuel savings, perceive resale value equal to 35% of gross price premium, and perceive future fuel price equal to the AEO projections. The 2016 perspective assumes that consumers value three years of fuel savings, perceive future fuel price equal to fuel price at time of vehicle purchase, and set the incremental resale value to 35% of the gross premium. Gross price premium is equal to: NHTSA 2012 projections in the baseline; NHTSA 2012 plus DOE estimate of ZEV plus NRC 'low most likely' adjustment in 2016 PP Low; and NHTSA 2012 plus TAR estimate of ZEV plus NRC 'high most likely' adjustment in 2016 PP High. The gross premium in COMET is obtained directly from the COMET model and accounts for ZEV and some NRC adjustments.

The potential for negative effects on new vehicle sales is not simply important for macroeconomic reasons; a slower volume of new vehicle sales diminishes the environmental benefits of the programs and creates safety risks (as consumers hold on to dirtier, less safe older cars longer), impacts consumers in used car markets since prices for used cars may rise, and affects the cost-benefit analyses of the regulatory programs in complicated ways.

Recommendations

Given our in-depth analysis of the three regulatory programs, the U.S. automotive industry, and the U.S. economy, we developed a series of 15 recommendations. Seven of these recommendations are for analysts, three are for regulators, and five are for legislators. Some of the recommendations flow directly from the macroeconomic analyses while others are stimulated by our qualitative policy analyses of the three programs and the industry.

For analysts, recommendations are designed to be helpful in the midterm review processes that are now focusing on the model-year 2022 to 2025 standards. For regulators and legislators, we ask more fundamental, probing questions about California's ZEV program. For the federal programs, we urge regulators and legislators to focus on refinements (e.g., schedule, fuel-price triggers, and off-cycle credits) rather than wholesale change. If the ZEV program is retained, a concerted effort should be made in states and communities to make it attractive for consumers to purchase and use a plug-in electric vehicle. We provide a wealth of information on how states and communities can increase readiness for electrification of the transportation sector of the economy.

For Analysts

1. Regulatory-reform options should be analyzed taking into account the unexpected drop in fuel prices that has occurred since the federal and ZEV rules were developed from 2009-2012, including the downward revision of fuel-price forecasts through 2025.

2. Regulatory-reform options should be evaluated based on the best available technology information, focusing on key issues that may distinguish one technology from another; realistic estimates of the impacts of multiple technologies need to be obtained.

3. When evaluating how consumers weigh fuel economy gains in new vehicle design, agencies should take into account new econometric studies that infer consumer valuations from short-term changes in fuel prices, decades of practical experience with fuel-saving technologies, and recent real-world experience with conventional hybrid engines.

4. Although agencies have made major steps forward in forecasting a realistic baseline set of vehicles for model years 2022-2025, refinements in the forecasted fleet are necessary in order to make valid comparisons to a regulated fleet subject to the 2022-2025 federal and ZEV standards.

5. Federal agencies should conduct a careful regulatory impact analysis of the combination of federal CAFE and GHG regulations and the ZEV program, including interactions between the programs that will influence incremental cost and benefit comparisons.

6. Federal agencies should estimate the impact of model year 2022-2025 standards on the volume of new vehicle sales. The vehicle-sales analyses are a crucial input to analyses of employment impacts, environmental and safety impacts, used-car market ramifications, and societal costs and benefits.

7. Agency analysts should estimate the macroeconomic impacts of combinations of regulations using at least several economic indicators (e.g., total employment, GDP, and real disposable income) and some regional or state disaggregation.

For Regulators

1. CARB and EPA should reconsider the design of the ZEV program, emphasizing ways to enhance the cost-effectiveness of the program and coordinate its requirements with the federal programs. If EPA determines that a ZEV-like program is in the national interest, EPA should consider expanding the California ZEV program into a national ZEV program that replaces or complements the federal CAFE and GHG performance standards.

2. Federal agencies should reconsider the schedule and explore a variety of refinements to the 2022-2025 performance standards to enhance cost-effectiveness.

For Legislators

1. The U.S. Congress should commission an independent assessment of the national costs and benefits of the California ZEV program, given the growing stringency of federal performance standards and fiscal policies designed to promote plug-in electric vehicles. Although federal agencies may decide to prepare such an assessment, the U.S. Congress should seek a separate look at the issue from an independent body such as the Congressional Budget Office or the National Research Council.

2. Both EPA and CARB are taking the position that a national cost-benefit assessment of the ZEV program is not permissible under the current statutory language of the Clean Air Act. Congress should consider whether to revise the Clean Air Act and require such a national cost-benefit assessment of ZEV waiver decisions.

3. The U.S. Congress should consider new legislation to fully harmonize federal CAFE and GHG programs, including the credit-trading programs, the penalties for non-compliance, and the compliance-flexibility provisions.

4. The U.S. Congress should commission a bipartisan commission of federal and state legislators and stakeholders to assess the future of consumer incentives for PEVs and FCVs, taking into account the recent reports from the National Research Council and new studies of the impact of consumer incentives in the U.S. and abroad. The Commission should consider how incentives should be coordinated with federal and state performance standards and when the incentives should be scheduled for phase out.

5. Given that older vehicles account for a disproportionate share of GHG emissions, smog-inducing pollutants, fuel consumption, and safety problems, legislatures should consider cost effective steps to accelerate the phase-out of older vehicles, taking into account lessons learned from the "cash-for-clunker" programs evaluated in the U.S. and Europe.

Our macroeconomic analysis does not include a societal cost-benefit analysis or an environmental or public health analysis of the regulations. Consequently, the study supplied here, by itself, does not address some issues vital to policy makers and stakeholders such as climate change, the public health impacts of pollution, and the overall societal benefits and costs of alternative standards. Therefore, policy makers should consider the findings of this macroeconomic analysis in conjunction with other forms of environmental, health, economic, and regulatory analysis.

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GLOSSARY

AFV: Alternative fuel vehicle

AT PZEV: Advanced technology partial zero-emission vehicle [California ZEV program classification]

BEV: Battery electric vehicle

CAFE: Corporate average fuel economy

CARB: California Air Resources Board

DOE: Department of Energy

DOT: Department of Transportation

EIA: Energy Information Administration

EISA: Energy Independence and Security Act

EPA: Environmental Protection Agency

EPCA: Energy Policy and Conservation Act

FCV: Fuel cell vehicle

GHG: Greenhouse gas

HEV: Hybrid electric vehicle

JNP: Joint National Program

MPG: Miles per gallon

NHTSA: National Highway Traffic Safety Administration

NRC: National Research Council

PEV: Plug-in electric vehicle

PHEV: Plug-in hybrid electric vehicle

PZEV: Partial zero-emission vehicle [California ZEV program classification]

RIA: Regulatory impact analysis

SUV: Sport utility vehicle

TZEV: Transitional zero-emission vehicle [California ZEV program classification]

ZEV: Zero-emission vehicle

1. PURPOSE AND SCOPE

This report covers the impacts of several regulatory programs that have four distinct but related public policy rationales: control greenhouse gas (GHG) emissions to slow climate change, enhance energy security by reducing oil dependence, increase consumer welfare by reducing the costs of operating motor vehicles, and boost economic development by creating "green jobs" in the automotive sector or boost consumer spending due to savings on gasoline expenses. These rationales are not rooted in the conceptual structure of welfare economics that is discussed at length in NHTSA (2012); instead, we frame them in ways that ordinary citizens and their elected representatives can comprehend.

1.1 Climate Change

The transportation sector will soon surpass the electric power sector as contributing the largest share (32.1% vs. 31.7%) of GHG emissions in the U.S. economy (EIA 2016; Sivak and Schoettle 2016b). The vast majority of GHG emissions associated with the transportation sector result from driving gasoline and diesel vehicles, specifically from the burning of gasoline and diesel fuels and resultant tailpipe emissions. A series of scientific reports, including those from the National Research Council of the National Academy of Sciences (Leung and Vail 2016) and the Intergovernmental Panel on Climate Change (IPCC 2014), stress that GHG emissions must be controlled to slow the pace of climate change. Within the transportation sector, cars and light trucks account for 56% of the GHG emissions in the U.S. (EIA 2016). If the U.S. is to honor its international commitments to GHG control, both those made in Paris under the auspices of the United Nations and those made in bilateral talks with China, control of GHG emissions from cars and light trucks must be a priority. Even absent these international commitments, no serious national climate policy can avoid addressing GHG emissions from the transportation sector.

The federal Corporate Average Fuel Economy (CAFE) standards, combined with the more recent EPA GHG standards, are the primary mechanisms through which the U.S. federal government regulates GHG emissions from the transportation sector. The federal programs are accompanied by two California programs aimed at slowing climate change: the California tailpipe emissions standards for GHGs and the ZEV regulation, which compels automakers to innovate through the invention, production, and marketing of ZEVs such as plug-in electric vehicles and hydrogen fuel-cell vehicles.

1.2 Energy Security

The Arab oil embargo of 1973-74 was associated with a rapid rise in the global price of oil and supply disruptions that impacted both the U.S. and its allies. Motorists were angered by rising fuel prices and long lines at refueling pumps in many states. Currently, threats to global oil markets could occur any day, since 20% of the world's oil supply and 40% of all oil traded in world commerce flow through the narrow Strait of Hormuz in the Persian Gulf, one of the most politically unstable areas in the world (Yergin 2011). Consequently, both energy security and national security may be enhanced by reducing U.S. dependence on petroleum (Wescott and Werling 2010).

Since the 1970s, the security rationale for CAFE regulation has receded in importance for a variety of reasons: the creation of the Strategic Petroleum Reserve, which can be deployed by the U.S. in periods of acute oil shortages; the removal of price controls in the U.S. market, which had exacerbated supply problems in 1973-1974; the surge of oil production in North America and in other non-OPEC countries, which has weakened the ability of OPEC to control global supplies and price; and a sharp reduction of U.S. oil imports, with allies Canada and Mexico now supplying almost 60% of U.S. oil imports (EIA 2016).

Some policy analyses continue to argue that the U.S. can moderate the global price of oil by curtailing the rate of U.S. oil consumption (Levi 2015; Sivaram and Levi 2015; Wescott and Werling 2010). However, that argument has been weakened as the U.S. share of global oil consumption has steadily declined, in part due to slower growth in travel volume in the U.S. and the success of CAFE regulation, but more so due to the rise in oil demand from

China and India (EIA 2016; Pugliaresi and Pyziur 2016). The U.S. share of global oil consumption has declined steadily from 30% in 1975 to about 20% in 2016, and that share is projected to dwindle further (e.g., as low as 10% by 2035) as the developing world grows (EIA 2016). As a result, NHTSA does not make quantitative projections of how much the world oil price is impacted by stricter CAFE standards (TAR 2016).

1.3 Consumer Welfare

A relatively new rationale for CAFE regulation is that it advances consumer welfare by compensating for tendencies among new vehicle purchasers to undervalue the long-run, personal benefits of purchasing enhanced fuel economy vehicles (NHTSA 2012a); for a skeptical view, see Gayer and Viscusi 2013. In addition to curbing externalities such as pollution, CAFE is aimed at correcting for this "internality" in consumer decision making (Allcott, Mullainathan, and Taubinsky 2014) by requiring automakers to sell consumers fuel-efficient vehicles that are less expensive on a total cost-of-ownership basis than the vehicles that consumers would have purchased and used without regulation (Fischer, Harrington, and Parry 2007; Helfand and Dorsey-Palmateer 2015).

The paternalistic nature of this argument is a source of consternation among libertarians and some rational-choice economists, but behavioral economists argue that ordinary consumers are particularly poor at making decisions that impose near-term pain for uncertain, long-term gain. This conundrum is a variant of what has become known in the academic literature as the "energy efficiency" paradox, which we explore in depth later in this report (Allcott and Greenstone 2012).

A complimentary rationale for the alleged under-provision of fuel-saving technology relates to the nature of decision making in the automotive industry (NHTSA 2012a). Automakers are uncertain about the extent of consumer demand for increased fuel economy, and consumer demand can change faster than the industry is able to adapt to the change. Making new passenger vehicles entails long lead times, since engineers must make decisions about the fuel economy of new vehicles long before the vehicles are brought to dealer showrooms for sale. Creating new technology, and the supply chain to support it, entail large capital investments that are irreversible. As a result, automakers are seen as "risk averse" toward making investments in new fuel economy technology, just as consumers are risk averse about paying a premium for an unfamiliar technology with uncertain payoffs (NRC 2015a). Fuel economy regulation is seen as a tool to overcome the alleged risk aversion in the automotive marketplace, even though risk aversion is not seen as a market imperfection in standard welfare economics.

1.4 Economic Development

In recent years, some proponents of the regulatory programs have begun to espouse economic-development arguments. Advocates argue that new investments in more sustainable automotive technologies will create jobs and spur the economy to higher levels of production and prosperity (Oge 2015; ICF 2015; Todd, Chen, and Clogston 2013).

For example, the Blue Green Alliance has released a study of the fuel savings and pollution reductions associated with the redesigned 2015 Ford F-150 pickup truck. The study highlights that CAFE regulation has stimulated new applications of Ford's Ecoboost engine and Ford's advanced electric power steering (EPS) system. Together, the two technologies contributed to a rise in the F-150's fuel economy from 15.9 MPG in 2010 to 19.2 MPG in 2015. The study finds that producing the EcoBoost "has meant reinvestment and job growth at Ford's Cleveland, Ohio, Engine Plant No. 1, which today employs 1,600 people." The EPS systems are made by the company Nexteer, which emerged from the bankruptcy of its parent company in 2010, and "today is the largest single employer in Saginaw County employing over 5,000 people and supplying the pickup truck market worldwide" (BlueGreen Alliance 2016).

The shift from steel to lightweight materials such as aluminum is also seen as having some positive impacts on economic development. In the fall of 2016, a joint venture of Constellium NV Amsterdam and UACJ Corporation of Tokyo launched a $150 million new factory in Bowling Green, Kentucky to supply aluminum production parts for automobiles (Irwin 2016b). Later in this report, we take a careful look at what the shift from steel to aluminum might mean for U.S. employment.

Economic development is a key consideration among California policy makers. The State of California currently has few facilities that produce auto parts or assemble vehicles for sale (CARB 2011a, 68–9). However, California investors and startups (e.g., Tesla) are playing a pivotal role in the push for electrification of the transport sector. Silicon Valley is seen as a potential source of innovation in vehicle offerings that could couple ZEVs with driverless technology (Ramsey 2016). California Air Resources Board Chair Mary Nichols, when issuing the 2012 ZEV requirements, was explicit about the economic-development rationale: “The Board’s action will create thousands of jobs, transforming California into the advanced car capital of the world. California is now in the pole position in the race to provide next-generation ultra-clean cars to the global market” (Clegern 2012).

At the national level, the Obama administration also portrayed the new NHTSA and EPA regulations as a strategy to help revive the domestic auto industry by stimulating companies to offer the fuel efficient cars that consumers have wanted and that will be demanded in Asia and Europe in the future (White House 2012). The administration also provided grants and federal loan guarantees (e.g., for companies that make lithium ion batteries for PEVs or HEVs) to facilitate a more rapid transition to a greener automotive economy (Canis 2013; Wescott and Werling 2010). In the regulatory impact analyses published in support of federal requirements, predictions were made that new jobs will be created in the green-technology industry. California’s regulatory impact analysis in support of the ZEV program makes a similar claim, noting that some of the leading companies that sell recharging stations for PEVs are based in California (CARB 2011a, 68–9).

Many economists question whether it is useful to focus on the employment impacts of regulation (e.g., see Mannix 2014). Economic models typically assume a full-employment economy, so more jobs gained or lost in one sector will, at least over time, be offset by more jobs gained or lost in another sector (Ferris and McGartland 2013). Nonetheless, the employment issue is so salient to citizens and politicians that it merits careful consideration (Coglianese and Carrigan 2013). In 2012, the U.S. Bureau of Labor Statistics made an effort to quantify “Green Goods and Services Jobs” within existing NAICS code industries (BLS 2017). Ideally, labor impact assessments should address not only changes in employment levels but average earnings and the geographic distribution of employment and earnings. Worldwide, the literature on employment impacts of transportation regulation amounts to a few dozen studies that are generally weak in their economic argumentation and fragmented in their scope and depth of issues covered (de Bruyn et al. 2012).

A different macroeconomic case for investment in more sustainable passenger vehicles has been suggested using total cost of ownership models. If, for example, PEVs will have lower ownership costs than gasoline vehicles in the long run, then policies that shift the auto industry to PEVs will save consumers money in the long run. Those consumer savings are then treated as a tax cut, stimulating more consumer spending in other sectors of the economy (de Bruyn et al. 2012; Roland-Holst 2011). An early variant of this approach, with application to PEVs, was prepared by the Global Venture Lab at the University of California at Berkeley. They found that replacing the internal combustion engine with PEVs in the U.S. would be a net plus for the national economy in the long run (Draper et al. 2008). Thus, the regulatory programs under study must be looked at from an economic as well as an environmental perspective.

1.5 Multiple Regulatory Programs

There are four federal and state regulatory programs aimed at the automobile sector. They are administered by three separate agencies: The U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHTSA), the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB).

NHTSA’s fuel economy standard for passenger vehicles is on a schedule to reach an average of 41 miles per gallon by model year 2021, as established by NHTSA in collaboration with the EPA. The EPA also set a schedule for reducing GHG emissions from model years 2017 to 2025, culminating in a GHG standard (typically expressed in grams of carbon dioxide, CO_2, per mile) that is equivalent to a CAFE average of approximately 54.5 miles per gallon in 2025. The figure of 54.5 miles per gallon is a compliance value based on laboratory testing of vehicles. Real-world fuel economy, reflected on fuel economy labels, can be 20% lower than the federal compliance value. As such, the 2025 compliance value corresponds to approximately 43 miles per gallon in typical driving conditions (Bond and Bunkley 2013). The Energy Information Administration, which also accounts for manufacturer use of compliance flexibilities and credits, projects that the new federal standards will lead to on-road fuel economy of 37.6 miles per gallon in 2025 (EIA 2016).

The development of EPA GHG standards trailed GHG standards in California, where limitations on GHG emissions from cars and light trucks were legislated in 2002 and promulgated in 2006. Currently, the California and EPA GHG standards, coupled with the CAFE program, are largely harmonized into a single national program for automakers, dubbed the Joint National Program (JNP). The federal government has committed to a midterm review process which, by April 2018, could lead to an adjustment in the structure or stringency of the model year 2022-2025 standards. EPA recently finalized an accelerated decision that the agency will not seek any changes to the 2022-2025 standards (EPA 2016a).

Separately, California's Air Resources Board (CARB) decided in 2012 to substantially increase the mandate for zero-emissions vehicles (ZEVs), such as PEVs and hydrogen fuel-cell vehicles (FCVs). By 2025, the ZEV regulation will compel the industry to sell enough ZEVs to reach approximately 15.4% of California's new passenger-vehicle fleet. CARB has recently updated that estimate to 18% (2016). Nine other states, including New York, have also adopted California's ZEV regulation.

Technically, the ZEV program is not included in the JNP, even though its objectives are similar (e.g., GHG control) and it is focused on the same products (cars and light trucks) produced by the same companies. The State of California is also undertaking a midterm evaluation of the ZEV program that is scheduled for completion in 2017, prior to completion of the federal midterm assessment (CARB 2015).

EPA and NHTSA (2012), in collaboration with CARB, are scheduled to release a final Technical Assessment Report (TAR) by early 2018 building on the TAR that preceded the 2012 EPA and NHTSA rulemakings and a draft TAR that was released for comment last year (TAR 2016). (We refer to it as the TAR rather than a product of a single agency because EPA, NHTSA, and CARB prepared it with inputs from other federal agencies). The draft TAR covered, among other topics, the range of potential compliance technologies, technology costs and fuel-saving effectiveness, consumer behavior, and national impacts on gasoline consumption and GHG emissions. It did not evaluate specific regulatory reform options.

In this report, we do not provide a comprehensive analysis of midterm review issues (for a discussion of additional issues not covered in this report, see Krupnick et al. 2014). Instead, we focus primarily on the potential impact of the regulations on macroeconomic indicators such as the volume of new vehicle sales, employment, GDP, and income. We explain in the next section why trends in new vehicle sales should be of concern to analysts, regulators, and legislators.

1.6 Why New Vehicle Sales are Important to Regulators

The rate of new vehicle sales in the U.S. economy is of obvious commercial significance to automakers, suppliers, and dealers. What is not so obvious is why federal agencies and CARB, in their pursuit of reductions in emissions of GHGs and other policy objectives, should invest analytic resources in understanding the impact of regulatory alternatives on new vehicle sales. As we show below, agency analysts have not yet devoted much quantitative analysis to this question and EPA (2016a), again in the most recent draft determination, chose not to perform a quantitative analysis of changes in new vehicle sales. We argue that changes in new vehicle sales due to regulation are not only important from a macroeconomic perspective, but have ramifications for achievement of environmental objectives, the safety of motorists, the welfare of used car buyers, and for a proper societal cost-benefit analysis of regulatory alternatives.

First, the automotive industry plays a significant role in the health of the U.S. economy (CAR 2011; Hilsenrath and Spector 2015; MEMA 2013; Prusa 2015). Based on data from the Bureau of Economic Analysis (BEA) (2016), motor vehicle manufacturing accounted for 9.6% of the gross output of the entire manufacturing sector in 2014 (with an average contribution of 10.2% over the 1997-2014 period). In addition, motor vehicle manufacturing and motor vehicle retail trade together contributed 2.7% of U.S. GDP in 2014 (with an average contribution of 3.1% over the 1997-2014 period) (BEA 2016).

This first rationale, which is macroeconomic in nature, is supported by the fact that the resurgence of the U.S. automotive sector played a significant role in the slow but steady recovery of the U.S. economy from the Great Recession of 2007-2009 (Goolsbee and Krueger 2015). Indeed, 2016 has been one of the strongest years of the economic recovery, a year when the auto industry achieved a record for new passenger vehicle sales. But the recovery has not been uniform across the country.

The regional economic impacts of changes in new vehicle sales are salient to policy makers, as the South and Midwest are more dependent on the auto sector than the West and East Coasts. The regional impacts of changes in vehicle sales, and the ripple effects on supply chains, may also influence the political sustainability of the federal programs, as the history of CAFE reveals that the program has vulnerabilities that are rooted in political conflicts—conflicts that are at least as much regional in nature as they are partisan or ideological (Luger 2005; Graham 2010a).

Second, the rate of new vehicle sales affects achievement of environmental objectives by influencing the pace of retirement of old vehicles from the fleet, also called the scrappage rate (Goulder and Stavins 2012; Jacobsen and van Benthem 2015). Older vehicles exert a disproportionate influence on national gasoline consumption and GHG emissions because they tend to be less fuel efficient than new vehicles. This effect is more pronounced for "criteria" pollutant emissions that impact local air quality. Old vehicles emit a disproportionate share of local pollutants related to smog and soot, in part because the emissions controls for local pollutants tend to work less effectively as a vehicle ages (Drake 1995; Gruenspecht 2001, NHTSA 2009). The rate of GHG emissions from a vehicle does not change significantly as a vehicle ages (Greene and Welch 2016). Nonetheless, slowing the rate of new vehicle sales hurts efforts at GHG control because newer vehicles, in part due to regulation, emit fewer GHG emissions than the older vehicles they replace.

Third, the rate of retirement of old vehicles is also linked to adverse safety outcomes for motorists. The designs of new vehicles today provide much better occupant crash protection than new vehicles designed in the 1990s (IIHS 2015a; NHTSA 2009). Thus, a slower rate of new vehicle sales will hamper progress in automobile safety, since motorists will be exposed to the elevated risks of traveling in older vehicles for a longer time.

Fourth, changes in the rate of new vehicle sales affect the welfare of used car buyers because the markets for new and used cars are linked. If some consumers are priced out of the new vehicle market, they may instead enter the used-car market, which has the effect of bidding up prices on used cars (Jacobsen and van Benthem 2015). While the used car buyer will certainly welcome the fuel savings that a fuel-efficient or zero-emission vehicle provides (Greene and Welch 2016), any increase in the price of the average used car is an affordability concern, since it is lower- and middle-income Americans who access the used-car market. A recent study has examined the distribution of costs and benefits of CAFE by income class, and it found that the program is regressive, in part due to price distortions in the market for used cars (Jacobsen 2013).

Finally, any regulatory impact on new vehicle sales is relevant to an appropriate societal cost-benefit analysis of the regulations, since consumer welfare is affected. This rationale is microeconomic in nature, insofar as consumers care about the attributes of their passenger vehicles. In 2011-2012, neither California nor the federal government found evidence that the regulations would exert an adverse impact on new vehicle sales, and therefore did not perceive a need to address this issue in societal cost-benefit analyses at the time (CARB 2011a; NHTSA 2012a; EPA 2012a). We seek to determine whether conditions in 2016 justify a careful inquiry into this question. To this end we conduct a Total Cost of Ownership (TCO) analysis in order to assess the direct and indirect costs of new vehicle ownership under the CAFE, GHG, and ZEV standards (Roosen, Marneffe, and Vereeck 2015).

1.7 Study Process, Deliverables, and Outline

In preparing the report, we have: (1) reviewed the regulatory impact analyses (RIAs) and related technical documents underpinning the federal and California requirements, including EPA's most recent determination not to revise the 2022-2025 standards; (2) reviewed academic and other literatures that assess the impact of CAFE and ZEV on new vehicle sales, or are relevant to such an assessment; (3) reviewed key trends in the industry, especially factors that have changed since 2009-2012 when the regulations in question were developed and finalized; (4) assessed related federal, state, and local policies that might be modified to complement the federal and California requirements; and (5) considered reforms of the federal and California requirements that are worthy of more in-depth analysis in the midterm review. We have also incorporated feedback offered by expert reviewers and an independent Peer Review Advisory Board comprising experts in energy, the environment, transportation, macroeconomic and microeconomic modeling, and the structure and operations of the global automotive industry.

With our focus on new vehicle sales in mind, this report provides a series of recommendations for consideration in the midterm review processes based on a quantitative analysis of the regulatory impacts. The recommendations fall into three categories: technical suggestions for regulatory analysts, regulatory reforms for consideration by federal and state regulators, and legislative policy options. The sequence of the recommendations presented in the report generally follows those three categories.

This final report follows from a first phase of research conducted during the summer and fall of 2015 and an accompanying phase I report, "Rethinking Auto Fuel Economy Policy: Technical and Policy Suggestions for the 2016-17 Midterm Reviews." This final report expands on the Phase I recommendations based on results from a series of modeling exercises. This report also reflects consideration of public comments received on the Phase I report and continued feedback provided by our Peer Review Advisory Board.

This report begins with an overview of the federal and ZEV standards, with information on the political history of these regulations. We then review regulatory compliance procedures and previous industrial impact studies, particularly those studies that investigate macroeconomic variables such as new vehicle sales and employment. We then describe the consumer and producer's perspectives, including the structure of the industry and its importance to the U.S. economy and in the recovery from the Great Recession of 2007-2009. Next, we review and critique previous macroeconomic modeling approaches used to determine the impacts of the federal and California regulations and then present our own modeling results. Following the modeling results and discussion, we consider regulatory reforms that could be made to improve the current standards. Finally, we present our specific recommendations for analysts, regulators, and legislators.

2. PUBLIC POLICY CONTEXT

2.1 History of CAFE

The Arab oil embargo of 1973-74 led to a quadrupling of world oil prices, rapidly rising gasoline prices, and fuel shortages that caused long lines at refueling stations in the U.S. The Congress and President Gerald Ford responded with new legislation aimed at reducing America's dependence on petroleum. Enacted in 1975, the Energy Policy and Conservation Act (EPCA) authorized the U.S. DOT, through NHTSA, to set minimum miles-per-gallon (mileage) performance standards for all new cars and light trucks sold in the U.S.

The legislation, followed by NHTSA rulemakings, contributed to a doubling of average new car mileage from 13 miles per gallon (MPG) in model year 1974 to 27.5 MPG in model year 1985. Market responses to higher gasoline prices contributed to the average mileage gains from 1974 to 1985, but the stricter CAFE standards also played a significant role (Nivola and Crandall 1995; Greene 1990; 1998; Shiau, Michalek, and Hendrickson 2009). Savings in petroleum use were significant but less than projected because sales of light trucks grew more rapidly than sales of cars during this decade (NRC 2002). The federal mileage requirements for light trucks were more permissive, starting at 17.2 MPG in 1979 and rising to 19.5 MPG in 1985. Moreover, entire segments of the light-truck fleet—e.g., pickup trucks with a gross vehicle weight rating (GVWR) of more than 8,500 pounds—were exempt from federal mileage standards (NRC 2002).

Market conditions changed in the late 1980s. In the face of declining fuel prices and financial concerns expressed by GM and Ford, the CAFE standards were relaxed in 1986 for cars and in 1990 for light trucks. GM and Ford apparently had product plans that would have achieved compliance with CAFE standards, but they were deprioritized in response to increased consumer interest in low fuel economy vehicles spurred by low fuel prices (Luger 2005, 130).

Efforts to legislate stricter CAFE standards gained momentum in 1990-1992 due to a new environmental concern: climate change from GHGs emitted by motor vehicles (Luger 2005, 163). However, opponents of CAFE standards blocked stricter legislation in the Senate using the filibuster threat.

When President Clinton took office in January 1993, the CAFE standards for model year 1993 were virtually unchanged from 1985. While President Clinton and Vice President Al Gore had pledged tighter CAFE standards during their campaign, a bipartisan coalition in Congress preempted the administration with a series of appropriations riders that barred increases in CAFE standards. The CAFE "freeze" started in model year 1996 and persisted throughout the Clinton administration.

The politics of CAFE changed during the George W. Bush administration, in part due to a rapid rise in average retail gasoline prices from approximately $1.50 per gallon in 2000 to more than $3.00 per gallon in 2008 (Graham 2010). The Bush administration decided to both tighten CAFE standards and, in response to suggestions from an independent study, reform the program to reduce safety risks (NRC 2002). In order to discourage unsafe downsizing of vehicles but reward substitution of lightweight materials, the CAFE standard for each manufacturer was adjusted based on the size distribution of its products (German and Lutsey 2010).

When Congress agreed to lift the CAFE freeze in 2002, NHTSA responded by raising light-truck CAFE standards from 20.7 MPG in model year 2004 to 22.2 MPG in 2007. NHTSA followed with the safety-based reform of the light-truck program that adjusted each automaker's CAFE requirement according to the size distribution of its products. For model years 2008 to 2011, NHTSA tightened the light-truck standards based on footprint (the area between the four wheels) to achieve an industry-wide average of approximately 24 MPG (Graham 2010a).

When the Democrats secured a majority in Congress in January 2007, they worked with the Bush administration on a major reform of the CAFE law included in the Energy Independence and Security Act (EISA) of 2007. Support for the legislation in Congress was widespread and bipartisan. Members were moved by environmental (i.e., climate change) and/or energy security rationales. EISA applied the footprint adjustment to cars as well as trucks, and established a minimum performance goal of 35 MPG by 2020 for the combined car and truck fleets. Higher standards were authorized for model years 2021 and beyond, with the specifics to be determined by technical analyses performed by NHTSA and EPA (Graham 2010).

Drawing on the authority given in EISA, the Obama administration tightened CAFE standards through rulemakings. A 2012 final rule sets standards that are expected to achieve an average of 41 MPG by model year 2021 (cars and light trucks combined), and a goal of 54.5 MPG, if met through fuel economy improvements alone, by model year 2025. The final CAFE standards for model years 2022 to 2025 will be set by a future NHTSA rulemaking, after the scheduled 2017-18 midterm review of the JNP.

2.2 California's GHG Standards for Motor Vehicles

The State of California has played an influential and innovative role in car-emissions control for decades (Carley, Betts, and Graham 2011). In fact, California began efforts to control motor vehicle emissions almost twenty years before the federal government applied its first standards to the auto industry in model year 1968 (MEMA v. EPA 1979).

During the Clinton and George W. Bush administrations, environmentalists and their allies in the California legislature became increasingly disenchanted with the federal government's handling of the CAFE program. Despite objections from the auto manufacturing industry and dealers, in 2002 the California legislature passed a new law, AB 1493, that authorized limits on GHG emissions from new motor vehicles sold in California. The law called for CARB to accomplish a sustained reduction in GHGs, and CARB set standards for vehicles starting in model year 2009. The standard set for model year 2016 is 250 grams of CO2 per mile, which is roughly equivalent to a 36 MPG CAFE requirement in model year 2016. Other states (e.g., New York and Massachusetts) began to join the California program, as concerns about climate change were increasing.

A legal battle ensued as to whether California possessed the authority to impose its own GHG standards (Graham 2010). Industry and the Bush administration argued that EPCA preempts any state regulation of motor vehicles related to fuel economy. California and environmentalists argued that the 1990 amendments to the Clean Air Act provide California with the power to set stricter auto emissions standards than the federal government. EPA, under the Bush administration, denied California the required waiver under the Clean Air Act, but a federal court ruled in 2007 that California does possess the authority under the Clean Air Act to set its own emissions standards for motor vehicles (EPA 2013).

When the Obama administration fashioned its policies from 2009-2012, the State of California was included as a key stakeholder in discussions with industry, labor, environmentalist, and consumer groups. The Obama administration decided to enact highly stringent CAFE standards, similar to what California had enacted for 2016 and was considering for 2017-2025.

As a result of the negotiations, the seemingly complex combination of the California GHG standards, the EPA GHG standards, and the NHTSA CAFE standards began to seem like a uniform national program because the compliance obligations for vehicle manufacturers were coordinated and measured only on a national basis. Specifically, on December 6, 2012, California adopted a "deem to comply" regulation that enables manufacturers to show compliance with California GHG standards by demonstrating compliance with federal GHG standards (EPA 2012b). Thus, at the present time, the California GHG standards do not impose any regulatory burdens on the auto industry that go beyond the federal requirements.

2.3 Federal GHG Standards for Motor Vehicles

The U.S. Supreme Court determined in 2007 that the EPA possesses the authority under the Clean Air Act to regulate GHG emissions from motor vehicles. Drawing on this authority, EPA made an "endangerment" finding in 2009, as GHG emissions from mobile sources were determined to be a contributor to climate change and therefore a threat to public health and the environment.

In response to a 2009 instruction from President Obama, EPA, in consultation with NHTSA, created an entirely new performance standard governing GHGs emitted by new cars and light trucks. The new standards, which have been finalized through model year 2025, are essentially equivalent to NHTSA's CAFE standards except that they are slightly stricter, though the EPA performance standards allow automakers to earn extra compliance credits by modifying air conditioners to reduce GHGs as well as for producing certain types of vehicles (e.g., ZEVs and PHEVs). EPA has taken the position that the EPA and NHTSA programs have been harmonized as much as possible, given the existing legislative authority for the two programs (EPA 2016a).

2.4 California's ZEV Program

In the 1990s CARB created a ZEV program that requires each vehicle manufacturer doing business in California to sell a specified percentage of ZEVs to consumers. Although originally seen as a program to help Los Angeles and other areas address unhealthy levels of airborne smog, today the ZEV program is also considered a tool to reduce the GHG emissions linked to climate change (CARB 2011a; Graham et al. 2014). The ZEV requirement was initially defined as 2% of new vehicle sales in 1998, ramping up to 5% in 2001 and 10% in 2003.

Due to technical, legal, and economic setbacks, the ZEV requirements were delayed and amended by CARB several times over the last 20 years. In their current form, as finalized in 2012, ZEV requirements mandate approximately 15.4% of ZEVs in each automaker's fleet by 2025 (CARB 2011a; CARB 2011b).

Section 177 of the Clean Air Act allows other states to adopt California's vehicle-emissions standards without being required to seek EPA approval when they do so (EPA 2013). To date, nine states have decided to replicate California's ZEV requirements. As a result, approximately 30% of national vehicles sales are covered by a ZEV program. Thus, assuming a national sales rate of 17 million vehicles per year, a 15.4% requirement in 30% of the market translates into 785,400 ZEVs in model year 2025 (for a similar calculation, see NRC 2015a). By way of comparison, almost 160,000 new plug-in vehicles were sold nationwide in 2016 (EDTA 2016). There is no question that the ZEV requirements for 2018-2025 will compel vehicle manufacturers to make significant investments in ZEVs.

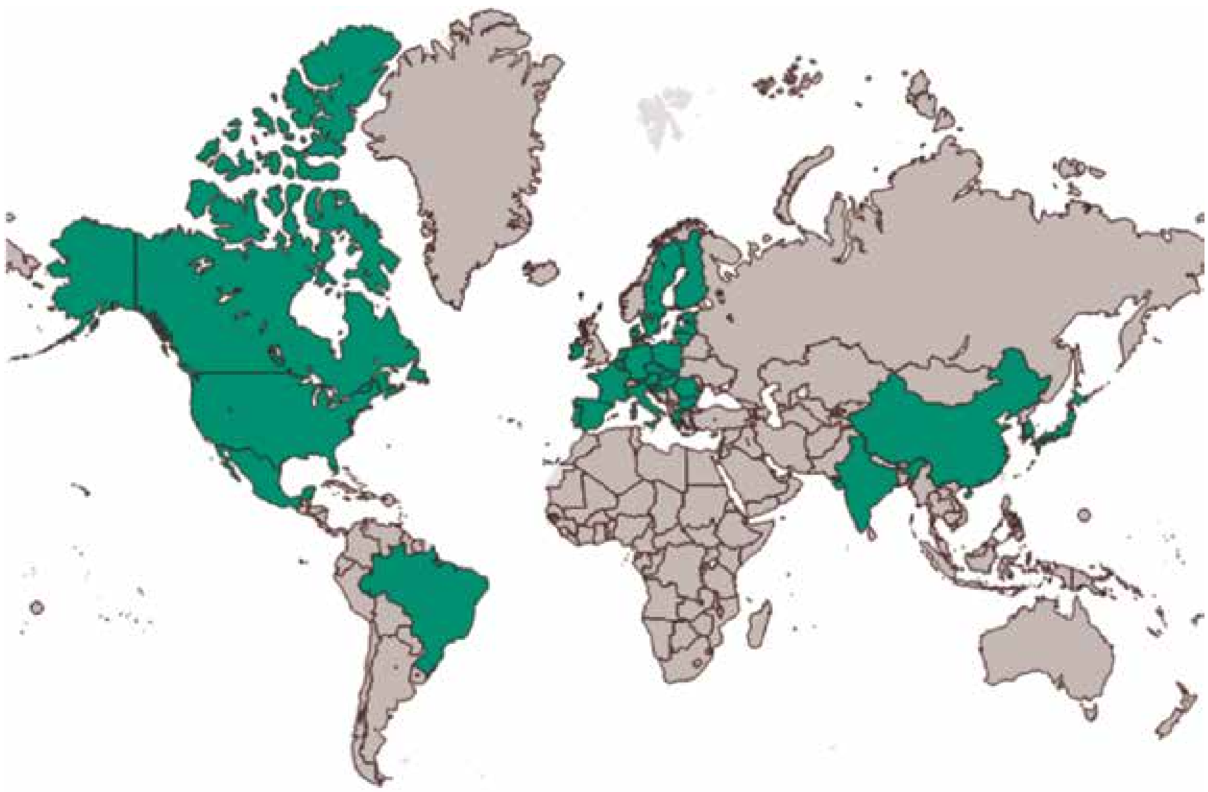
In the absence of the ZEV mandate, it is questionable whether the array of federal and state incentives for PEVs would be sufficient, given low fuel prices, to stimulate investment in an electric vehicle industry (Kahn 2016; NRC 2015b). EIA's 2015 modeling showed that market forces alone, coupled with gradually rising fuel prices and falling PEV prices, would cause only 2% of new vehicle sales in 2040 to be PEVs (EIA 2015b).

In this report, the term *plug-in electric vehicle* (PEV) is used to describe any vehicle that draws electricity from the electrical grid. A *battery-electric vehicle* (BEV) is a PEV that relies entirely on electricity for propulsion power (e.g., the Nissan Leaf). A *plug-in hybrid electric vehicle* (PHEV) is a PEV that draws power from both a gasoline engine and a battery pack (e.g., the Toyota Prius Plug-In). A *fuel cell vehicle* (FCV) is powered by a hydrogen fuel cell (e.g., the Hyundai Tucson SUV). A conventional *hybrid electric vehicle* (HEV), such as the well-known Toyota Prius, operates on both gasoline and battery power but does not have the plug-in feature. PEVs and FCVs are considered the most likely propulsion systems to be used by automakers to achieve compliance with the ZEV regulation.

2.5 Regulatory Systems Worldwide

The U.S. is not the only country to enact fuel economy standards or GHG standards for new vehicles. There are now nine governmental bodies around world that have enacted or proposed such standards: U.S., Brazil, Canada, China, the European Union (EU), India, Japan, Mexico, and South Korea, as displayed in Figure 2.1. The automobile production in these jurisdictions accounts for 80% of the global vehicle market (Kühlwein, German,

Figure 2.1. Countries with Fuel Economy or Greenhouse Gas Standards, as of December 2016.



and Bandivadekar 2014). The regulatory programs around the world vary in structure, stringency, flexibility, drive cycle, and vehicle certification test procedures.

Comparing fuel economy requirements in different countries is no small task. The U.S. measures fuel economy using a weighted average of testing procedures for city and highway driving conditions. The EU and China use the New European Driving Cycle (NEDC) to measure fuel economy, which similarly considers the differences in urban and extra-urban driving. Japan uses the JC08, which takes a weighted average of a cold start measurement and a hot start measurement. The United Nations Working Party on Pollution and Energy is developing a worldwide standard—the Worldwide Harmonized Light-Duty Test Cycle (WLTC)—which is intended to replace the NEDC and potentially other approaches. These fuel economy test cycles differ in several ways, including starting conditions, duration, distance, mean and maximum velocity, stop phases, and acceleration (Kühlwein, German, and Bandivadekar 2014).

The International Council on Clean Transportation (ICCT) developed a series of conversion factors that allow for the comparison of fuel economy standards among these countries. Table 2.1 shows a comparison of the fuel economy requirements for the U.S., the EU, Japan, and China, using the ICCT's conversions to keep all comparisons consistent with the CAFE-MPG approach. Although the U.S. standard appears to be more lenient than the European, Japanese, and Chinese standards, the U.S. auto market, as we explain below, has fewer small cars and more light trucks than the EU, Japan, and China.

Like the U.S., other countries such as Canada, India, Japan, and South Korea, and regions such as the EU, have enacted compliance incentives to encourage automakers to offer advanced technology vehicles such as PEVs (IEA 2016). Sometimes called "super credits," these incentives tend to give greater compliance credits to PEVs than would be justified by a strict accounting of their lifecycle GHG emissions.

At the present time, no other country in the world has implemented a regulatory program similar to the California ZEV mandate. In late 2016, Quebec became the first Canadian province—and the only other jurisdiction in the

Table 2.1. Fuel Economy Standards for Light-Duty Vehicles (MPG) in Selected Countries

	U.S.	EU	Japan	China
2017	35.4			
2018	36.5			
2019	37.7			
2020	38.9		45.9	47.7
2021	41.0	56.9		
2022	43.0			
2023	45.1			
2024	47.4			
2025	49.7	72.5-82.3*		

Note: *This standard is being studied but has not been adopted.

Source: ICCT. http://www.theicct.org/sites/default/files/info-tools/pvstds/Global_PV_data_20150803.xlsx

world—to enact a ZEV program. The Quebec program also includes an $8,000 purchase rebate, public grants for charging stations, and HOV lane access for some drivers of PEVs.

Some legislatures around the world are beginning to consider more radical proposals to boost the future of PEVs. The idea is to prohibit or phase out the PEV's dominant competitor: the internal combustion engine. Bills of this sort are apparently under consideration in the Netherlands, Norway, Germany, Austria, and India (C. White 2016; Mitchell 2016).

The strength of the demand-side pull for PEVs also varies considerably around the world due to differences in gasoline prices, electricity prices, public incentives for purchase and use of PEVs, the availability of recharging infrastructure, and other factors (IEA 2016). With lithium ion battery prices declining due to innovation and economies of scale in production, forecasts are being made as to when the total cost of ownership of a PEV will be comparable to the total cost of ownership of a gasoline or diesel-powered vehicle.

Primarily due to differences in gasoline prices at the pump, one study estimates that parity will be reached sooner in the EU (2021) and China (2025) than in the U.S. (post-2025) (Clark and Campbell 2016). In recent years, sales of PEVs have risen faster in the EU and China than in the U.S., with peak penetration rates highest in the Netherlands (23%) and Norway (10%). In 2015, China had a higher PEV penetration rate (1.0%) than the U.S. (0.7%), primarily due to enlarged public incentives and subsidies in China and low fuel prices in the U.S. (IEA 2016).

All large-volume automakers sell vehicles in multiple countries, yet they are looking to make as many vehicles as possible from a single global platform. Global automakers also face a global investment community, and investors are becoming more aggressive in their expectations of technological innovation from the industry (Institutional Investors Group on Climate Change 2016). Therefore, it can be expected that, during product planning and production-volume decisions, automakers will consider consumer demands, investor demands, and compliance obligations in multiple countries and regions (Laing 2017). On the other hand, the U.S. vehicle market is so large that global automakers can afford to tailor some product offerings specifically to the U.S. market. As the industry globalizes, it is reasonable to expect that regulators will come under increasing pressure for harmonization or mutual recognition of regulatory requirements.

3. REGULATORY COMPLIANCE AND CREDIT TRADING PROCEDURES

In order to appreciate the complexity of the regulatory system faced by automakers, it is useful to review how manufacturer compliance with the standards is determined and the penalties for noncompliance. The regulatory programs also provide some flexibility for manufacturers, and the terms of those provisions are explored briefly below.

3.1 NHTSA's CAFE Program

Congress has specified that CAFE standards be set at the "maximum feasible level," taking into account technological feasibility, economic practicability, the effects of other standards on fuel economy (e.g., safety or smog standards), and the need to conserve energy. The CAFE standards for individual manufacturers are specified in two product categories: passenger cars and light trucks. A manufacturer's standard is determined by computing the sales-weighted average, specifically the harmonic mean, of the mileage targets for individual vehicles in a manufacturer's fleet. Requirements for individual vehicles vary based on their size (footprint): vehicles with larger footprints have lower minimum fuel economy targets than vehicles with smaller footprints.

To assess manufacturer compliance, the average fuel economy of vehicles distributed for sale by a manufacturer is compared with the manufacturer's CAFE standard. A manufacturer's passenger car fleet is compliant if the aggregate fuel economy of this fleet is at or above the stated standard. A separate compliance determination is made for the manufacturer's light trucks. Most large-volume manufacturers sell both cars and light trucks. Additionally, under the CAFE program, manufacturers' car fleets are divided into domestic and foreign. Domestic vehicles are those that contain 75 percent or more U.S., Canadian, or post-NAFTA Mexican content (by value). Manufacturers' domestic and foreign car fleets must separately be in compliance with CAFE standards.

The CAFE regulatory program is credit based, such that each manufacturer has a credit account that can be debited or filled based on its compliance in a given model year. Any time a manufacturer exceeds compliance targets it earns a certain number of credits. Manufacturers can address under-compliance by using credits accumulated in previous model years or by paying a civil penalty set at $14 per tenth of an MPG. The value of the civil penalty was increased in the summer of 2016 (from $5.50 per tenth of an MPG) pursuant to the Federal Civil Penalties Inflation Adjustment Act of 2015. The Act requires federal agencies that administer civil monetary penalties to adjust penalty values to capture inflation that was previously unaccounted for in penalty values, and that they annually adjust penalty values to account for inflation henceforth (Office of the Federal Register 2016). The $5.50 penalty rate had not been adjusted by NHTSA since 1997.

With respect to credits, manufacturers can (1) carry excess credits earned in a given year forward up to five consecutive years following the model year in which these credits were earned ("carry forward provision"); (2) carry credits backward up to three consecutive years prior to the model year in which credits were earned ("carry backward provision"); (3) transfer excess credits earned for one vehicle product category to account for deficits in another; or (4) purchase credits from other manufacturers that have excess credits. However, vehicle manufacturers must be wary about relying heavily or primarily on credits. Regulatory agencies have a tendency to discount the value of accumulated credits through rulemaking actions, and manufacturers may face public, shareholder, or investor protests if they rely primarily on credits rather than innovative new vehicle designs.

3.2 EPA's GHG Standard

Similar to the CAFE program, EPA's vehicle emission standards for GHGs are set according to vehicle footprint, wherein larger footprint vehicles have more permissive GHG emissions targets than smaller footprint vehicles. Also like the CAFE program, EPA's program relies on a credit banking system.

Manufacturers under-/over-complying with GHG emissions standards can carry credits forward or backward to account for compliance shortfalls, or trade credits with other manufacturers. The incorporation of certain types of vehicle technologies or vehicle design features earns manufacturers extra credits. For example, manufacturers earn credits for including efficient air conditioning systems that reduce refrigerant leakage and rely on alternative refrigerants with lower climate change potential. Manufacturers also earn credits for solar panels and engine start-stop technology, as well as for improvements in vehicle aerodynamics. When the benefits of the vehicle technology/design features are not reflected in emissions testing procedures, the credits awarded to the manufacturer are termed "off-cycle" credits.

Further, under EPA's program, manufacturers earn extra credits for certain types of advanced vehicles. In 2017, each BEV and FCV distributed for sale by a manufacturer will count as two vehicles. By 2021, the multiplier will be decreased to 1.5. PHEVs will be multiplied by 1.6 in 2017 and 1.3 in 2021. Additionally, electric and fuel cell vehicles will count as emitting 0 grams of carbon dioxide equivalents per mile during the 2017-2021 period, irrespective of upstream emissions. During the 2022-2025 period, there is no multiplier for specific vehicle technologies, and emissions related allowances are based on vehicle sales. Since these credits expire in model year 2021, they may not be relevant to the midterm review, which focuses on model years 2022-2025. The presence of such credits can be seen as an effort to coordinate federal regulatory policy with the California ZEV program.

When the EPA launched the new GHG program, it did not assign zero credit balances to all vehicle manufacturers. It recognized that some manufacturers (e.g., Toyota) had accumulated significant GHG credits from 2009-2011 and allowed those credits to be transferred to the start of the EPA program. In other words, in 2013 Toyota was posted with 86 million EPA credits at the start of the 2012 model year, credits that can be used until the 2021 model year (when they expire) (Nelson 2013a).

Manufacturers need to ensure, if they plan to use credits under the NHTSA program, that they also have sufficient credits under the EPA program. While some German manufacturers have a history of paying fines under the CAFE program, the Big Three have feared that they might be liable for civil damages in stockholder lawsuits if they paid fines, or they may squander political capital or public image (Jacobsen 2013; Kleit 2004). In any event, paying fines as a compliance technique will not work in the future because it is not a viable option under the EPA program. EPA has the discretion to administer fines in the range between $0 and $37,500 per vehicle, and there is little guidance as to how the agency intends to exercise its discretion. The EPA can also go beyond fines and stop a company from selling vehicles if it does not meet the standard or have credits to cover any deficit (Leard and McConnell 2015).

The EPA credit program was also designed to help start-up PEV manufacturers. New PEV manufacturers are permitted to accumulate credits each year relative to their sales volume. Those credits can then be sold to other vehicle manufacturers who are confronting an EPA compliance deficit. EPA reported in its 2015 annual report that Chrysler and Mercedes Benz were buying EPA GHG credits; Nissan, Honda and Tesla were selling them (EPA 2015).

3.3 The ZEV Regulation

A "ZEV state" is one that has adopted California's entire "Advanced Clean Cars Program," including requirements for control of smog, soot, and GHGs, and regulation to encourage greater numbers of ZEVs. The ZEV regulation requires that manufacturers selling vehicles in a ZEV state earn a certain number of "ZEV credits," which corresponds to a percentage of the total number of passenger cars and light-duty vehicles distributed for sale in the state. The ZEV regulation currently applies to large- and intermediate-volume manufacturers. Currently, large-volume manufacturers are defined as those that sell more than 60,000 vehicles per model year in California. Intermediate-volume manufacturers are defined as those that sell 4,501 to 60,000 vehicles per model year. Starting in 2018, any manufacturer that produces more than 20,000 vehicles per year will qualify as a large-volume manufacturer.

A ZEV is a vehicle that does not produce tailpipe emissions during operation and, given current technology, must be a BEV or FCV. They are referred to as pure ZEVs (CARB 2013). Currently, under the ZEV regulation, CARB also grants credits for extremely low polluting technologies (i.e., those that are not quite zero emitting) to help automakers achieve regulatory compliance. These other types of vehicles include those categorized as Transitional ZEVs, Partial ZEVs, and Advanced Technology Partial ZEVs. Table 3.1 lists the types of vehicles that are included in each of CARB's ZEV categories. The number of credits awarded for any particular kind of ZEV currently depends on characteristics like vehicle type, how far the vehicle can travel on a zero-emission fuel source, and a vehicle's fast refueling capability.

Fast refueling capability is the ability to refuel to 95% capacity within 10-15 minutes, depending on a vehicle's zero-emission fuel range (i.e., similar to the rate of traditional gasoline or diesel fueled vehicles). A provision specific to fast refueling allows manufacturers to earn additional credits beyond the baseline credits based on demonstrated fast refueling capability. Currently, manufacturers can earn credit for up to 25 vehicles based on performing 25 fast refueling events on just one vehicle. The fast refueling credit will be eliminated altogether in model year 2018.

While the ZEV program does currently allow manufacturers to earn credits for transitional ZEVs, advanced technology partial ZEVs, and partial ZEVs, the awarded credit is lower for these vehicles than for pure ZEVs. Further, manufacturers can only fulfill a limited fraction of their requirements with non-pure ZEV vehicles. Table 3.1 also shows the range of credits that can be earned for different types of vehicles in model years 2012-2017 and 2018-2025. Note that no credits are provided for HEVs or partial ZEVs starting in model year 2018.

CARB publishes formulae that determine how credits vary based on the design of a ZEV and how credits translate to compliance percentages. For each model year, CARB sets a Total ZEV Percentage Requirement and a Minimum ZEV Floor Requirement. The Minimum ZEV Floor Requirement specifies the percentage of credits that must be earned with pure ZEVs alone. The Total ZEV Percentage Requirement can be met with credits earned from a combination of pure ZEVs and other allowed technologies. Table 3.2 shows the Minimum ZEV Floor and Total ZEV Percentage Requirements for model years 2018-2025 for large-volume manufacturers. Once manufacturers meet the ZEV floor requirement, they can meet the remaining ZEV requirement with credits from TZEVs.

Beyond 2025, ZEV requirements are expected to become increasingly stringent to help California accomplish its goal of reducing statewide GHG emissions to 80% below 1990 levels. In support of this goal, California Governor Jerry Brown recently issued a target of having ZEVs comprise 100% of new vehicle sales in 2050 as part of a non-binding agreement with several U.S. states, Quebec, and several European countries (Siders 2015).

Intermediate-volume manufacturers are granted some leniency in achieving ZEV requirements through model year 2017 because they generally have less revenue and capacity to engage in research and development than

Table 3.1. Credit Ranges by ZEV Vehicle Type

ZEV Vehicle Type	Definition	Vehicle Type	Credits Model Years 2012-2017	Credits Model Years 2018-2025
ZEV	Zero Emission Vehicle	Battery electric vehicle, hydrogen fuel cell vehicle	1 to 9 depending on range and fast-refuel	1 to 4 depending on range
TZEV	Transitional Zero Emission Vehicle	Plug-in hybrid or extended range electric vehicle, hydrogen internal combustion engine vehicle	1 to 3 depending on technology	0.4 to 1.3 depending on range
PZEV	Partial Zero Emission Vehicle	Extremely clean conventional vehicle	0.2	-
AT PZEV	Advanced Technology Partial Zero Emission Vehicle	Natural gas vehicle, hybrid electric vehicle	> 0.2 to 3 depending on technology	-

Source: Adapted from Center for Climate and Energy Solutions; http://www.c2es.org/us-states-regions/policy-maps/zev- program

Table 3.2. ZEV Requirements by Model Year

Model Years	Total ZEV Percent Requirement	Minimum ZEV Floor	TZEVS
2018	4.5%	2.0%	2.5%
2019	7.0%	4.0%	3.0%
2020	9.5%	6.0%	3.5%
2021	12.0%	8.0%	4.0%
2022	14.5%	10.0%	4.5%
2023	17.0%	12.0%	5.0%
2024	19.5%	14.0%	5.5%
2025	22.0%	16.0%	6.0%

Note: Each year over the regulatory period, manufacturers are subject to a total ZEV percentage requirement. Manufacturers must earn a certain number of credits from ZEVs only, equating to the minimum ZEV floor percentage requirement described in this table. CARB allows manufacturers to fulfill the remaining ZEV requirements with credits from TZEVs.

Source: CARB, 2012b; http://www.arb.ca.gov/regact/2012/zev2012/fro2rev.pdf

do large-volume manufacturers (CARB 2014). Through model year 2017, intermediate-volume manufacturers are allowed to meet ZEV requirements entirely with PZEVs. Starting in 2018, they will also be allowed to meet requirements solely through TZEVs.

Manufacturers that over-comply with ZEV requirements (i.e., earn more ZEV credits than required in a given year) can bank those credits for future use to accommodate compliance shortfalls, or sell excess credits to other manufacturers. Conversely, under-complying manufacturers must pay a fine or purchase credits from manufacturers with excess credits. Starting in 2018, manufacturers will be required to make up a ZEV credit deficit within one year (CARB 2014). While small-volume manufacturers—those producing 4,500 or fewer units per year—are not currently regulated under the ZEV program, they may earn, bank, market, and trade credits for the ZEVs and TZEVs they produce and deliver for sale (CARB 2012b, 3).

Under the federal Clean Air Act, states are allowed to opt in to California's ZEV program. The following nine states currently participate in the ZEV program (listed in parentheses are the dates each state joined the California program): New Jersey (2004), Connecticut (2004), Vermont (2005), New York (2005), Maine (2005), Rhode Island (2005), Massachusetts (2005), Oregon (2006), and Maryland (2007). States that opt to follow the California standards must adopt them in their entirety (even as they are amended by CARB) in order to maintain consistency and thereby simplify the compliance burdens on automakers.

Currently, manufacturers can apply the credits they earn for the sale of pure ZEVs in one ZEV state to count toward meeting regulatory requirements in any other ZEV state (CARB 2011a). This credit transfer allowance is referred to as the "travel provision," and is set to end in 2017. By eliminating the travel provision for pure ZEVs, CARB is compelling a minimum number of BEV sales in each of the ZEV states (CARB 2012c). The travel provision for FCVs has been extended indefinitely to allow ZEV states ample time to develop infrastructure to support these vehicles and to implement policies that will facilitate their adoption and use. Currently, there is not adequate hydrogen refueling infrastructure in any state to support widespread use of FCVs (Fleming 2015).

CARB also offers automakers the opportunity to pursue compliance through the "Optional Section 177 State Compliance Path" (Optional Path). This compliance path provides automakers the flexibility of meeting their ZEV obligation in three regional pools: California, other western states, and eastern states. The western pool includes all states west of the Mississippi River, excluding California. The eastern pool includes all ZEV states east of the Mississippi River. Thus, if a manufacturer's sales are short in Massachusetts, the company can compensate with a surplus of sales in another eastern ZEV state (e.g., New York). Credits transferred between states in the same regional pool transfer at full value. Credits transferred across regional pools do so at a reduced value. The

Optional Path also reduces TZEV requirements in 2015-18 model year and pure ZEV requirements in 2018-2020 model year for non-California ZEV states. Manufacturers choosing the Optional Path are subject to increased pure ZEV sales quotas in the 2016-17 model year in non-California ZEV states.

The fines for noncompliance with ZEV standards range from $5,000 per credit shortfall in California to up to $25,000 per credit shortfall in some northeastern ZEV states. No large auto company has yet paid a fine under the ZEV program because the requirements have been relaxed numerous times before a deadline, when it was apparent that multiple companies would not comply. Moreover, trading ZEV credits between companies may seem preferable to paying a fine, and both Tesla and Nissan have been selling ZEV credits for the last several years. On a regular basis, CARB reports the volume of ZEV credit trades but not prices. Some information on prices can be inferred from corporate annual reports and information reported by companies to the Securities Exchange Commission.

Overall, while the array of credit provisions under the ZEV program introduce some regulatory complexity, CARB maintains the position that these will provide some compliance flexibility and allow manufacturers more lead time for developing ZEV vehicle technologies (CARB 2011a). On the other hand, some analysts argue that the ZEV regulation has so much compliance flexibility that it will not stimulate enough commercialization of BEVs and PHEVs (Shulock 2016). Shulock (2016) argues that certain reforms are needed to make the requirements for ZEVs stricter: (1) increase the overall ZEV percentage requirements; (2) mandate that at least 25% of credits used to comply must come from pure ZEVs (BEVs or FCVs) produced in that model year, which would limit the practice of trading and banking and discourage over-reliance on PHEVs; (3) change the credit formula so that it awards fewer credits per vehicle, thereby forcing automakers to produce more ZEVs; (4) reduce the value of previously earned ZEV credits, thereby ensuring more production of ZEVs in the future; and (5) tighten the requirements on qualified PHEVs, especially their all-electric range, or enlarge the number of “high performance” PHEVs that may be used for compliance. Thus, CARB is being encouraged to make the ZEV program more prescriptive, at the same time that several of the compliance flexibilities in the program are scheduled for expiration.

4. THE CONSUMER'S PERSPECTIVE

An auto manufacturer's ability to meet federal and ZEV standards is contingent upon consumers purchasing its vehicles. Therefore, it is not enough for manufacturers to design and produce fuel-efficient and zero-emission vehicles; consumers must also prefer these vehicles to those that consume more fuel but potentially offer better performance, more desired features, or a lower price.

From 2009 to 2016, new vehicle sales recovered robustly. Thus, EPA (2016a) argues that there is no evidence that the federal programs reduced consumer welfare from 2009-2016.

It should be kept in mind, however, that fuel prices were relatively high and rising for most of that period, thereby spurring consumer interest in fuel economy. In effect, consumer preferences and regulatory forces were aligned, at least from 2009-2014. The industry has had much more difficulty making progress on fleet-wide average fuel economy since fuel prices collapsed in the U.S. and remained relatively low in 2015 and 2016 (Sivak and Schoettle 2017).

The situation will likely be different from 2017-2025. The federal and ZEV standards are scheduled to increase in stringency much more rapidly from 2017-2025 than they did from 2009-2016. The U.S. also appears to be entering a sustained period of relatively high levels of consumer confidence and low fuel prices (EIA 2016), with the possibility of some real growth in household income (Proctor, Semega, and Kollar 2016). As a result, regulators and manufacturers are likely to confront more misalignment between consumer preferences and regulatory demands, since consumers may not be as incentivized to favor fuel-efficient vehicles.

4.1 Consumer Decision Making about Transportation

For the retail consumer, purchasing a vehicle is a major investment of household income, second in size only to the decision to buy a house or condominium. Indeed, purchasing and operating a passenger vehicle is so expensive that some households try to organize their lives so that they need not own a personal vehicle. As a result, the share of young people seeking a driver's license declined from 1983-2014 (Sivak and Schoettle 2016a).

In the years ahead, auto manufacturers and dealers will be targeting the next generation of consumers (Gen Y: those born between 1977-1994) to replace lost sales from the aging Baby Boomers, implying that the preferences of Gen Y will influence the market. Similar to previous generations, Gen Y enjoys driving, provided driving is low cost, convenient, and accommodates varying personal lifestyle demands (B. Brown et al. 2014). Some segments of Gen Y seem to be more interested in living in urban settings and relying on alternative modes of transportation. The success of car-sharing services such as Uber, which are familiar to Gen Y, is expected to taper the demand for personal vehicles in the future (Litman 2016; Gardner 2016).

Some residents of urban centers can already access alternatives to owning a passenger vehicle (e.g., carpooling, biking, walking, or taking public transportation), but such alternatives are actually losing market share to the private automobile. More than three-quarters of U.S. workers drove to work without anyone else in the vehicle in 2012, up from 64% in 1980. The amount of carpooling has declined by 50% over the same period. The number of trips supplied by public transit systems has declined from 6% in 1980 to 5% in 2012. The number of employees working at home is growing rapidly, but that trend does not necessarily curtail interest in vehicle ownership (Tavernise and Gebeloff 2011; Shah 2013). In short, America's "love affair" with the personal vehicle is not likely to end soon.

The classic car-shopping studies (e.g., see NRC 1996, 82–83), have confirmed that consumers typically engage in a two-step process: first, consumers choose a type or class of vehicle (e.g., sedan, pickup truck); then they select a specific make and model within that class. Some consumers exhibit a high degree of brand loyalty over their lifetime while others do not. It should not be assumed that, at the outset of a search, all consumers understand the differences between sedans and crossovers or SUVs and minivans.

Vehicles differ in so many dimensions—price, financing arrangement, performance, appearance, safety, fuel economy, ride height, repair records, seating capacity, trunk space, towing capability, and so forth—that it is rational for buyers to simplify the decision by focusing on a subset of dimensions that are most important to them. There are established theories in behavioral economics (e.g., bounded rationality, satisficing, and decision making heuristics) that predict that consumers will make simplifications when they face complex decisions (Simon 1976; Kahneman, Slovic, and Tversky 1982; Thaler and Sunstein 2008).

To simplify the decision-making process when purchasing a new vehicle, consumers tend to focus on a limited number of dimensions. A 2013 survey of over 300,000 new vehicle buyers found that consumers rate reliability, durability, quality of workmanship, value for the money, and manufacturer's reputation as most important in their decision to purchase a vehicle. Fuel economy was listed as the 11th most valued feature—behind such features as seating comfort—even with gasoline prices at $4.02 per gallon at the time of survey distribution. The same survey revealed that a mere 5% of respondents who purchased vehicles were willing to pay a premium for environmentally friendly features.

JD Power and Associates reported similar findings from their 2015 Initial Quality Study (Murtha 2015). More than 84,000 new vehicle owners were asked, several months after purchase, about the factors that were important to them in their recent purchase of a new car, truck, van, or SUV. In order, the most commonly cited factors were expected reliability, exterior styling, previous experience with brand/model, reputation/reviews, ride/handling, price/payment plan, fuel economy, safety, quality of workmanship, and availability of 4-wheel drive. Thus, while fuel economy is salient, it is among a variety of important factors that consumers consider.

In the long run, widespread use of car-sharing services may simplify the valuation exercise for consumers, since purchasing a new vehicle (with all of its complexity) will be replaced by the purchase of a single trip. The provider will presumably charge the consumer for the trip based on cost and vehicle quality, and purchase vehicles to attract customers yet minimize lifecycle costs (i.e., original equipment costs plus operating and maintenance costs). However, the U. S. is a long way from widespread reliance on car-sharing services.

4.2 New or Used Vehicle?

In conjunction with a consumer's decision to consider a vehicle purchase, a classic dilemma is whether to purchase a new or used vehicle. Each year more than 40 million used cars are sold in the U.S., more than double the count (about 17 million) of new vehicles sold. The average selling price of a used vehicle ($17,000) is about half the average selling price of a new vehicle (Rogers 2014). When manufacturers design and market new vehicles, they are acutely aware that the consumer typically has the option to retain their existing vehicle longer or make a purchase in the used vehicle market.

4.3 Fleet Buyers

Auto makers cannot focus exclusively on the wants and needs of the individual retail purchaser. Government and commercial fleets account for about 20 percent of new passenger vehicle sales in the U.S., depending on the year (Snyder 2016). Fleet buyers are budget constrained and thus focus on purchase price when comparing vehicles. When fleet buyers also incur the operating costs of the vehicle, they will be sensitive to fuel expenses and the total cost of ownership. After fleet vehicles are used for a period of time, they typically find their way back to dealers and the used-car market.

4.4 How Retail Buyers Finance their Purchases

A consumer cannot purchase an appealing, well-designed vehicle unless they can finance the purchase. Since most households lack sufficient savings to pay $30,000+ for a new vehicle or $17,000 for the average dealer-offered used vehicle, the buyer will typically seek a loan to help pay for the purchase.

The loan may be offered by a bank, finance company, or credit union (direct lending). Alternatively, many dealers offer attractive financing for customers as a convenience, sometimes with backing from the vehicle manufacturer. About 70-80% of retail purchases of new vehicles are financed with loans (DeBord and Rudegeair 2014).

To make sure that consumers do not purchase a vehicle that they cannot afford, consumers are asked to construct a monthly spending plan. From monthly after-tax (take home) pay, the consumer subtracts housing and utility payments, typical credit card payments, and typical set asides for emergencies. The residual from this calculation is considered the maximum the consumer can afford to put toward monthly payments for a vehicle (including taxes, insurance and other vehicle-related expenses).

With support from manufacturers, dealers may offer a variety of incentives to make a vehicle affordable such as price discounts or cash rebates on certain models or favorable terms in financing arrangements. A loan agreement used to stipulate that the loan be paid off after five years (60 months). In recent years, the average loan duration has steadily increased, sometimes to 70 months (Mello 2016). The interest rate that the consumer can qualify for will depend on their credit history and how their credit score compares to other purchasers.

An alternative financial arrangement is a lease, where the consumer is allowed to use a vehicle for a fixed number of months and miles (e.g., 15,000). While using the vehicle, the consumer is responsible for wear and tear and repairs. At the end of the lease, the consumer returns the vehicle to the dealer, and may have the option of purchasing the vehicle at that stage.

For vehicles with untested innovations, leasing is a crucial option. Most PEVs are sold in leasing arrangements to ease consumer concern about the longevity of the electric propulsion system and to permit the consumer to readily return the PEV when an improved PEV is available.

4.5 Key Product Categories

Products in the U.S. industry are typically divided into two broad categories: cars and light trucks (crossover vehicles, sport-utility vehicles [SUVs], pickup trucks, and minivans), also called "light-duty passenger vehicles." The distinction between a car and light truck is not always clear and the definitions are not always consistent; indeed, EPA defines some crossovers as cars for regulatory purposes (EPA 2015).

A light truck vehicle is not defined by size or mass, but by whether it possesses all-wheel drive. From the consumer's perspective, the light truck will also typically have the ride height that many American consumers have come to enjoy (NRC 2015a). The evolving federal regulatory definition of a light truck—and the more permissive CAFE standards for trucks—has played a pivotal role in product innovation within the industry for decades (Sallee 2010).

In order to remain globally competitive, high-volume producers have gravitated to single platforms where multiple vehicles—including both cars and light trucks—can be produced for different regions of the world. However, the platforms must be flexible enough to tailor characteristics of the vehicles to consumer preferences in different regions. Thus, it is useful to consider some of the special features of the U.S. auto market that make it different from the comparably sized market in Europe and the larger and rapidly expanding market in Asia.

As a starting point, consider the volume and market shares of each vehicle product category in the U.S. in 2015, as shown in Table 4.1. Perhaps the two most distinctive features of the U.S. passenger vehicle market are the sustained popularity of the pickup truck and, in the last decade, the emergence of the crossover SUV coupled with the decline in interest in the large SUV. Most recently, the large market for mid-sized sedans has lost ground to the increasingly popular crossovers. The midsized sedan was the largest segment for decades but in 2016 it was overtaken in U.S. sales volume by the compact crossover (Bunkley 2016).

Table 4.1. Product Categories by Sales Volume and Market Share, 2015

Product Category	Total Vehicles Sold in America (2015)	Market Share in America (2015)	Example Model
Small/Compact Car	2,999,980	17.26%	Toyota Corolla/Matrix
Midsized Car	2,974,893	17.11%	Toyota Camry
Large Car	315,320	1.81%	Chevrolet Impala
Luxury Car	1,234,528	7.10%	BMW 3-series
Pickup	2,474,669	14.24%	The Ford F-Series
Crossover	5,208,360	29.96%	Honda CR-V
SUV	1,247,387	7.18%	Ford Explorer
Van	927,093	5.33%	Chrysler Pacifica

Source: Ward's Auto, 2016a

4.6 Choices: New Fuel-Saving Technologies and Alternative-Fueled Vehicles

Since 2012, substantial real-world experience has been acquired with fuel-saving technologies such as a refined gasoline engine and alternative fuel vehicles (AFVs) like the advanced diesel engine, HEVs, and PEVs. This experience with new fuel-saving technologies can help us learn more about consumer decision making. We do not address some alternative fuels (e.g., natural gas and propane) that seem unlikely candidates for rapid expansion in the light-duty fleet between now and 2025.

Since the CAFE program was revived in model year 2004, manufacturers have made steady progress in producing and selling vehicles with higher average fuel economy. Real-world vehicle fuel economy has increased from about 20 miles per gallon in model year 2005 to 25 miles per gallon in model year 2015 (EPA 2016d). Roughly half the gains have been attributed to better technology, as opposed to consumer shifts to more fuel-efficient products (Khanna and Linn 2013). The gains in model years 2014 and 2015 (preliminary data) slowed a bit, as consumers have increasingly purchased vehicles with lower average fuel economy (e.g., crossovers, pickup trucks, and other SUVs), virtually nullifying the effects of better technology (EPA 2015; 2016e; UMTRI 2016). Preliminary data for model year 2016 suggest progress toward higher fleet-wide fuel economy is continuing, though at a lower rate than observed previously (EPA 2016d). We explore here some key technologies and AFVs and their impact on consumer decision making.

4.61 Refinements to the Gasoline Engine

In the last five years, the bulk of the technology-based gains in fuel economy have been accomplished through refinements to gasoline-powered vehicles. Those refinements include variable valve timing, multi-valve engines, gasoline direct injection, turbochargers, 6+ speed transmissions, and continuously variable transmissions. Only a small portion of the gain in average fuel economy is attributable to AFVs such as HEVs, diesels, and PEVs (EPA 2015; 2016e).

There is much debate within the industry about the extent to which the 2025 standards will be met through continued refinements to gasoline-powered vehicles as opposed to AFVs (e.g., see Duleep 2016). On the one hand, some suppliers project that automakers will be able to achieve the 2025 federal EPA and NHTSA standards through a wide variety of refinements to the gasoline engine, without investing in alternative propulsion systems (Sedgwick 2014). On the other hand, several leaders of vehicle manufacturers have indicated publicly that significant sales of PEVs and/or FCVs will be necessary to comply with the federal standards in model year 2025 (Rechtin 2012; Beene 2015b).

An indication of the difficult path ahead is that only 3% of the model year 2015 vehicle production could meet the 2025 NHTSA goal for fuel economy and the 2025 EPA standard for GHG emissions. Those few vehicles are predominantly PEVs and FCVs (EPA 2015; 2016e). In its most recent industry-compliance report (EPA 2016c), EPA reported that three manufacturers (Fiat-Chrysler, Mercedes, and Kia) did not meet the 2015 EPA GHG standard without use of credits, and BMW met the 2015 standard with no margin of safety. The average manufacturer's compliance margin declined in 2015 by almost 50% compared to 2014 (EPA 2016c).

NRC (2015a) examined a wide range of fuel-saving technologies—some already in use, others in development—that could be used by manufacturers to help achieve the 2025 standards. According to the report, large gains in fuel economy are feasible through additional refinements to the gasoline engine, though new fuel-saving technologies will add to the price of new passenger vehicles with uncertain ramifications for consumer acceptance and new vehicle sales.

NRC (2015a) did not estimate compliance costs or impacts on new vehicle sales. But, they (2015a, 275) did find, for a mid-sized car, that the cumulative technology costs to meet the 2025 standard could be 11 to 56% greater than NHTSA's 2012 estimate. NRC (2015a) did not model the cost ramifications of the compliance flexibilities in the CAFE and EPA programs and did not consider the ZEV program. NRC (2015a) also calls for more research into the uncertain aspects of consumer decision making about fuel economy.

4.62 Substituting Lightweight Materials

Since 2012, an important development in vehicle fuel economy has been the contribution of mass reduction to fuel economy gains. Specifically, manufacturers are reducing mass by using lighter-weight materials. Downsizing vehicles is less attractive, in part because the federal programs impose stricter mileage and GHG control requirements on vehicles with smaller footprints (NRC 2015a).

In addition to its direct fuel-consumption benefit, a vehicle made with lighter materials can function with a smaller powertrain, braking systems, and crash management structures (NRC 2015a, 107). Because of these benefits, each 10% drop in vehicle weight can achieve a 5.7 to 7.4% drop in fuel consumption at a cost of approximately $700 per vehicle. Larger weight reductions require disproportionately larger costs, such as $1,600+ per vehicle for a 20% mass reduction (NRC 2015a, 113).

The NRC (2015a, 264) fuel-saving estimates for a 20% weight reduction are approximately 20% larger than NHTSA assumed in 2012. If this estimate holds up in the midterm review, weight reduction will look more attractive to consumers and manufacturers than NHTSA and EPA originally estimated.

Ford Motor Company is already making much greater use of aluminum (rather than steel) in its largest-selling vehicle: the F-series pickup truck. The 2015 F-150 is fitted with aluminum instead of steel for every panel except the firewall, resulting in a 700 pound loss of weight compared to the steel-based 2014 F-150. In effect, the new truck has a high-strength steel frame coupled with an aluminum body. For this rugged-vehicle application, the aluminum is strengthened with extra thickness and heat-treating after it is formed. EPA reports that Ford's 2015 F-150, due to weight reduction, a smaller engine, and other fuel-saving features, is much closer to compliance with the 2025 EPA truck target for GHG emissions and is rated overall at 22 MPG (Williams 2015b).

Ford's decision has triggered an aggressive competitive response from steelmakers. Advanced high-strength, light-weight steels (AHSS) that cost less and have fewer lifecycle GHG emissions than aluminum are being marketed. AHSSs have been incorporated into the 2015 Chevrolet Colorado, the 2015 Ford Edge, and the 2015 Nissan Murano (AISI 2015).

Given recent developments, the midterm reviews should address some issues with lightweight materials that were not considered adequately in the 2012 RIAs but may be of concern to consumers. These issues include not only lifecycle GHG emissions, since an older study touted the advantages of aluminum (Ungureanu, Das, and Jawahir 2007), but also new concerns regarding occupant safety and repair costs.

The Insurance Institute for Highway Safety (IIHS) tested both the four door F-150 SuperCrew and the smaller SuperCab version in a battery of crash tests (IIHS 2015a; Valdes-Dapena 2015). Both Ford trucks performed well in normal frontal and side-impact tests. However, the smaller version did not perform well in IIHS's new overlap frontal crash test. About one-quarter of serious and fatal injuries in real-world frontal crashes are caused by "small overlap" frontal impacts, such as collisions with trees and utility poles. IIHS noted that Ford added additional structures to the F-150 SuperCrew that prevented passenger compartment intrusion in the test. The SuperCab version, without the additional structures, experienced crushing of the passenger compartment and a risk of foot and leg injuries. The crash-protecting structures of the SuperCrew have since been added to the SuperCab. For 2016, both the SuperCrew (four doors, full back seat) and the SuperCab (two smaller rear doors, compact back seat) qualify as Top Safety Picks.

IIHS also tested the new 2015 F-150 in low-speed crash tests. The results show more vehicle damage and 26% greater repair cost than steel-based models (Valdes-Dapena 2015; IIHS 2015b). GM contends that the aluminum in the F-150 is susceptible to puncture under sharp loads (Colias 2016a). A related concern is that property-damage insurance premiums could rise due to aluminum substitution. Ford counters that early real-world experience with the 2015 F-150 shows lower repair expenses than experienced with the 2014 F-150 (Hirsch 2015b; Williams 2015a).

In summary, lightweight materials will have a significant role to play as the 2025 deadline for the federal standards approaches. Regulatory analysts need to go beyond initial cost comparisons and disclose any differences in safety and repair records/costs for different materials that may be of concern to consumers.

4.63 Advanced Diesel Technology

A major difference between Europe and the U.S. is the penetration of the diesel engine into the passenger vehicle market. Diesels account for 53% of new passenger vehicle sales in Europe compared to 2.75% in the U.S. (Clark and Sharman 2015).

Fuel taxes are generally 3 to 4 times higher in the EU than in the U.S., which generates consumer interest in the diesel due to its superior fuel economy. Europe also imposes higher taxes on gasoline than diesel fuel while the U.S. taxation favors gasoline over diesel fuel. The emission-control regulations for smog and soot from diesels have historically been stricter in the U.S. (especially in California) than in Europe, which has been a factor in facilitating the expansion of the diesel market in Europe and restrained diesel penetration in the U.S. Favorable diesel fuel prices have also been a factor (Cames and Helmers 2013; Walsh 2011).

As concerns about GHGs have become as important as fuel efficiency, the case for expanded use of diesel technology has weakened somewhat. Diesel fuel produces 15% more CO2 emissions per gallon than gasoline (NRC 2015a). Thus, even though diesel engines can achieve 30% higher fuel economy ratings than gasoline engines and thereby help comply with NHTSA's fuel economy requirements, the diesel engine offers only a 12% advantage in carbon emissions compared to a gasoline engine. As a result, shifting from a gasoline to a diesel engine may not, by itself, be sufficient to bring a light-duty passenger vehicle into compliance with EPA's 2025 GHG requirements.

For the consumer, the cost premium on a diesel engine (above a gasoline engine) is substantial. For a mid-sized sedan, the manufacturing cost premium for a base engine is approximately $3,300 to $3,600 per vehicle (NRC 2015a), or at least $4,600 (with a 1.5 retail markup). For applications to large pickup trucks and SUVs, the cost premium (without retail markup) will exceed $5,000. However, the Ford diesel reportedly lasts 100,000- 200,000 miles longer than the gasoline engine and is said to deliver better torque and towing capability (Ford Truck Enthusiasts 2014). Thus, the consumer may see significant practical value in a diesel-powered truck compared to a gasoline-powered truck.

The price of diesel fuel is also higher than the price of motor gasoline. The price spread is typically about 10%, but the spread fluctuates. EIA forecasts that the spread will be 12% ($3.49/$2.95) in 2025 (EIA 2015b). The persistence of the unfavorable price spread for diesel is due in part to tax policy, as the long-run marginal cost of refining oil into diesel fuel is generally less than it is for gasoline.

Some recent news reports about the Volkswagen diesel scandal have suggested that VW's violations may jeopardize the commercial future of all light-duty diesel technology in the U.S. and Europe (Clark and Sharman 2015). This pessimistic scenario seems unlikely since other German manufacturers (BMW and Daimler), using different emissions-control technology (e.g., selective catalytic reduction with aqueous urea added to the exhaust gas before the catalyst), have had success with their diesel-powered sedans in the U.S. and Europe (Diesel Technology Forum 2017).

In September 2016, GM announced plans to offer a diesel option on the 2018 Chevrolet Equinox—the company's best-selling small SUV—seeking to gain a competitive edge on the Ford Escape and Honda CRV (Colias 2016b). GM has also added a diesel option to the Chevrolet Cruze hatchback, in part to woo customers disaffected by the Volkswagen scandal (Truett 2016a). In 2018 Ford will offer a diesel option on the F-150, seeking to appeal to customers with strong requirements for towing and hauling (Martinez 2017).

Advanced diesel technology is a promising federal compliance technology for vehicle manufacturers, but the price premium for the consumer will be significant. Moreover, a large investment in a diesel strategy will not help companies comply with the ZEV regulation and will help less with EPA's GHG requirements than with NHTSA's fuel economy requirements.

4.64 Conventional Hybrid Technology

Exemplified by the Toyota Prius, the HEV has one integrated propulsion system that draws power from two sources: a combustion engine and an electric motor. Hybrid models vary in the design of their propulsion systems, but they all reduce fuel consumption in three ways: capturing for reuse some of the energy lost during braking (through "regenerative braking"), reducing energy losses during idling, and enabling engine downsizing (NRC 2015a, 130). Mild hybrids are distinct from full hybrids because they embody only some of the fuel-saving features of a full hybrid (e.g., a mild hybrid may have only a stop/start system to reduce idling losses).

A full hybrid can deliver 30+% gains in fuel economy and corresponding declines in GHG emissions. For example, the Hyundai Sonata hybrid delivers 51.5 MPG compared to 36.6 MPG for its gasoline counterpart; the Toyota Camry LE hybrid delivers 57.4 MPG compared to 38.2 MPG for the Camry (NRC 2015a, 132). Since full hybrids often have other features that differ from gasoline comparators, it can be difficult to isolate the fuel economy gain that is attributable to hybridization per se (German 2015).

HEVs are costly because they rely on integrated propulsion systems. For a mid-sized car, full hybridization may entail $2,000 to $2,700 in direct manufacturing costs in high-volume production, or an extra cost to the consumer of at least $3,000 (assuming a retail markup of 1.5). For applications to large pickup trucks and SUVs, the cost penalty for full hybridization is likely much larger (NRC 2015b).

From a performance perspective, HEVs tend to have faster acceleration times from 0 to 30 miles per hour but slower times from 0 to 60 miles per hour compared to gasoline engines (NRC 2015a, 154). In terms of reliability, the nickel batteries in the Toyota Prius have been highly reliable over many years of use but some cautious consumers may have doubts about battery reliability (Consumers Union 2016; Carrns 2013). Thus, there may be some perceptions of hybrid performance or reliability that deter some buyers.

Due to the commercial success of the Toyota Prius (the #1 selling car in California in both 2012 and 2013), a reputable forecaster projected ten years ago that full hybrids might capture 7% of U.S. market share by 2015 (Shamit 2008; Hirsch 2015a). That forecast was overly optimistic, as HEVs accounted for less than 3% of sales in 2015 and 2016.

National hybrid sales grew steadily from 2000-2008, were hurt by the Great Recession in 2009-2010, but surged to their peak in 2013 (547,095). Despite a recovering new-vehicle market, hybrid sales declined in 2014, 2015, and 2016 (DOT 2015; Addady 2016). Survey researchers find that hybrids are favored by many respondents in "intent to purchase" studies, but many of those respondents do not follow through and purchase an HEV (Popiel 2011).

For a company like Toyota, which has a strong edge in HEV technology, one might think offering hybrid engines on a wide range of Toyota products would be a fruitful federal compliance strategy. Indeed, Toyota has expanded its offerings of HEVs significantly over the last several model years into a "Prius family" of vehicles (Undercoffler 2016a).

Following Toyota's lead, the number of HEVs offered industry wide grew from 24 in 2009 to 55 in 2016 (DOE 2016). However, the growth in HEV market share over the same period has been slower, from 2.4% to 3.0%, and the HEV share actually declined in 2015 and 2016 (McLain 2016a; Addady 2016; Libby 2014).

A variety of explanations have been offered for the unexpectedly slow growth of the HEV market share through 2014 and the more recent declines in market share. Each of the following explanations has some supporting evidence or reasoning.

From a financial perspective, the consumer is looking at a long payback period for a hybrid investment. Although the cost of producing hybrids is declining over time, there are still significant price premiums for HEVs compared to comparably-sized gasoline vehicles (German 2015). The recent 2015-2016 decline in gasoline prices has further lengthened the payback period (see our hybrid payback analysis in Appendix I).

Governments have hurt hybrids by rescinding the state and federal tax credits for HEV purchases (e.g., a federal income tax credit up to $3,400 for HEVs expired at the end of 2010) (Beresteanu and Li 2011; Diamond 2009; Chandra, Gulati, and Kandlikar 2010; Gallagher and Muehlegger 2011). Governments have also restricted HEV access to HOV lanes, which had helped boost HEV sales in California and other congested areas (Sewell, Mather, and Bloomekatz 2011; J. R. Healey 2011). California once awarded HEVs partial credits under the ZEV program but CARB has ruled that HEVs will no longer qualify for ZEV credits. The justification for these changes is that HEVs are a known technology that should no longer be subsidized. However, recent surveys have demonstrated that a majority of U.S consumers have a very poor understanding of what HEVs are, so it is hardly surprising that consumers are not willing to pay a premium for them (Kurani, Caperello, and TyreeHageman 2016).

HEVs are also confronting intensified competition from new technologies. Some consumers perceive greener versions of gasoline-powered vehicles (e.g., Ford's Ecoboost engine) as more cost-effective than an HEV. On the other hand, the growth in public subsidies and social marketing for PEVs has channeled "early adopters" away from HEVs to PEVs.

Proponents of the HEV argue that Toyota's new version of the Prius C, which appeared in most showrooms in early 2016, will be crucial in determining the near-term commercial success of HEVs (McCormick 2015). Consumers may have refrained from buying the old version of the Prius because they knew that the new version would be out soon. Preliminary 2016 sales figures for the new Prius suggest, however, that the multi-year decline in Prius sales has not been reversed (McLain 2016a).

Toyota's experience with the new 2016 RAV4 Hybrid, a crossover vehicle, will also be instructive. It is rated at 34 MPG-city, 31 MPG-highway, 33 MPG-overall compared to the gasoline version ratings of 22 MPG-city, 29 MPG-highway, 26 MPG-overall. The RAV4 Hybrid also delivers more horsepower and torque than the gasoline version. Toyota has priced the RAV4 Hybrid only $700 above the gasoline version and the new vehicle is receiving excellent reviews from consumer-facing car publications (Courtney Jones 2016; Edmunds 2016b; Sabatini 2016). One prominent car reviewer describes the RAV4 Hybrid as a "No Brainer Gas Saver," which is a blunt way of saying that the $700 premium is readily recouped in fuel savings.

WHAT HAPPENED TO THE FORD ESCAPE HYBRID?

Ford Motor Company, from 2004-2012, offered a hybrid version of its popular Ford Escape SUV. It was the first full hybrid offered on a light-truck product; the vehicle was visually indistinguishable from its gasoline-powered counterpart. Although the Escape SUV was a highly successful product, sales of the Escape Hybrid never exceeded 15% of total Escape sales. See Table 4.2 below for sales data on the Ford Escape, both total and hybrid sales, coupled with information on the fuel-price environment. In this insert, we consider the story of the Ford Escape Hybrid from the consumer's perspective.

Ford terminated the Escape Hybrid SUV starting model year 2013, when an entirely new Escape SUV was offered. The 2013 Escape was offered with the less expensive Eco-Boost gasoline engine. Ford argued that the Eco-Boost accomplished much of the fuel economy gain of a hybrid at a fraction of the cost of a hybrid system, although EPA certification data show that the fuel economy gain of the hybrid significantly exceeded that of the Eco-Boost.

Ford also launched the dedicated 2013 C-Max Hybrid, seeking to serve a variety of customers, including those interested in a compact SUV; it was Ford's first hybrid-only line of vehicles (Edmunds 2016a). Critics counter that the C-Max Hybrid is not a utility vehicle and lacks the all-wheel drive that attracted almost 50% of the Escape Hybrid buyers (Berman 2011; Voelcker 2016). EPA classifies the C-Max as a large car rather than an SUV. Because the C-Max is a dedicated model (with no gasoline counterpart), it is difficult—like it is with the Prius—to draw any comparative inferences about consumer valuation of fuel economy. Nonetheless, the C-Max has not been selling significantly better than the Escape Hybrid, except for its strong first year on the market (2013 sales: 28,956). So we turn to why the Escape Hybrid did not sell that well.

Table 4.2. Commercial Experience with the Ford Escape Hybrid, 2004-2012

Model Year	Total Escape Sales	Escape Hybrid Sales	% Hybrid	Gasoline Prices ($/gal)
2004	183,430	2,993	1.63*	1.895
2005	165,122	18,797	11.38	2.314
2006	157,395	20,149	12.80	2.618
2007	165,596	21,386	12.91	2.843
2008	156,544	17,173	10.83	3.299
2009	173,044	14,787	8.54	2.406
2010	191,026	11,182	5.85	2.835
2011	254,293	10,085	3.97	3.576
2012	261,008	1,441	0.55**	3.680

Notes: Gasoline prices are the retail national average--including all grades and all formulations--in nominal dollars. *partial year of sales due to late start; **Ford had already publicized new EcoBoost and C-Max offerings for model year 2013.

Sources: Ford Motor Company, as presented and referenced in Wiki; EIA, 2016.

The Escape Hybrid was offered with two trim levels: base and Limited. The comparator vehicles are the Escape XLS (base) and Escape Limited. Three engines were offered: I4, V6, and Hybrid with I4, but the Escape XLS was not offered with a V6. Moreover, the 2010 Escape Hybrid base vehicle had much more content than the Escape XLS (base), including the following 12 special features: 6-way power driver seat, premium cloth seats, digital keypad, compass (external temperature), trip computer, overhead console and storage, climate control, leather steering wheel, dual illuminating vanity mirrors, electrochromatic inside rearview mirror, satellite radio with 6 months service, and USB with external media control (Edmunds 2016a).

With respect to content, the Ford Escape Limited Hybrid and Limited Non-Hybrid are a closer comparison, as both were stacked with content but there were four differences, each favoring the Hybrid: sunroof and sunshade, automatic temperature control, front dual zone air conditioning, and power glass tilting and sliding roof (Edmunds 2016a).

The pricing of the Ford Escape (all variants) rose steadily during the Escape Hybrid's lifetime and the size of the difference between the MSRPs was not consistent from year-to-year. Depending on the year, which two vehicles are being compared, and whether or not adjustments are made for other content differences, the gross price difference for the Escape Hybrid ranged from +$3,000 to +$7,840.

During most of the Escape Hybrid's life, buyers were eligible for a $2,000-$3,000 federal income tax credit; a larger credit for the 2WD version, a smaller one for the 4WD; and the credit was somewhat larger for the second-generation Escape Hybrid (IRS 2006; IRS 2009; KRT 2005). The credit began to decline in size when Ford reached a production cap of 60,000 hybrid units in late 2008; the credit fell to zero in the spring of 2010. Some states added their own cash incentives for hybrids, plus access to the HOV lanes. And Ford and its dealers offered some incentives in some years in some locations.

The bottom line is that the average net price premium for an Escape Hybrid purchase, during the vehicle's lifetime, was probably in the range of $2,000 to $5,000, after taxes and incentives. It is not known whether the Escape Hybrid was priced adequately to achieve profit, since Ford's cost information is proprietary.

One car review makes a slightly different but useful comparison: the list price of the 2010 Ford Escape Hybrid ($29,860) relative to the list price of the average 2010 compact SUV/Crossover, which was $5,413 lower (Axelgeeks 2010). The net Escape Hybrid premium, after the federal tax credit, was $3,413. The reviewer also noted that the rated horsepower of the Escape Hybrid was slightly higher than average while trunk space was slightly smaller in the Escape Hybrid. Otherwise, the difference boils down to price and fuel economy.

Critics of the first-generation Ford Escape Hybrid, offered from model year 2004 through 2007, raised a variety of concerns, though it is far from clear how many consumers felt this way. Concerns were raised about somewhat diminished horsepower and torque compared to the gasoline version, especially the V-6 (Vanderwerp 2004; Edmunds 2016a). The air conditioner would not work when the gasoline engine was off. The stop-start system was a bit primitive, and thus the first movements from a stopping position were somewhat rough (noise and vibration). The regenerative brakes also felt a bit "spongy" to some drivers.

The second-generation Escape Hybrid, offered from 2008-2012, addressed all of these concerns: performance was boosted while the reprogrammed engine smoothed out the stop-start feature, so it felt more responsive like regular hydraulic brakes; an electrically driven air conditioning compressor was added; and, under full acceleration, with both batteries and the gasoline engine engaged, the second-generation Ford Escape Hybrid was considered quicker than the gasoline version. Despite the improvements and rising gasoline prices, sales of the Escape Hybrid did not increase.

The big, and undisputed, advantage of the Ford Escape Hybrid is much higher fuel economy compared to its gasoline comparators, somewhere between 6 and 10 miles per gallon (e.g., 29 vs 23 MPG for AWD or 33 vs 23 MPG for FWD, depending on exactly how the comparison is made). If the owner drives 15,000 miles per year, they would save 135-197 gallons of fuel per year, with corresponding reductions in the number of refueling trips. At an average fuel price of $2.50, $3.00, and $3.50 per gallon, the annual savings in fuel expenses were expected to be $338-493, $405-$591, and $473-$690, respectively. Those savings (undiscounted) are not enough to fully offset the premium price in a short time horizon (say, 3 years) but are large enough to recoup the price premium over the 15-30 year lifetime of the vehicle.

Thus, a short consumer time horizon on fuel savings (and/or a high discount rate on future fuel savings), in conjunction with an aversion to the purchase price premium, is a plausible explanation for the limited commercial appeal of the Ford Escape Hybrid. There are some possible complementary explanations. Some consumers may have been uncertain about the longevity of the batteries and other electrical components, though Ford was offering an 8-year, 100,000 mile warranty on hybrid powertrain components. There was probably some mistrust of the EPA fuel economy labels, especially as they applied to hybrids in real-world driving (Woodyard 2013a). And SUV buyers may simply have very limited interest in fuel economy.

Toyota, though, remains cautious, predicting that only 10-15% of RAV4 buyers will select the hybrid (Woodyard 2016a). The 10-15% range is remarkably similar to the take-up rate for the Ford Escape Hybrid.

Some analysts argue that mild hybrid systems are a more cost-effective investment than a full conventional hybrid, and that helps explain why the market has shifted away from the full hybrid. Although the term "mild hybrid" is somewhat ill-defined, it generally refers to selected components of a full-hybrid system. The "micro-hybrid system" refers to the combination of a stop/start system to reduce idling losses with replacement of alternator functions (e.g., an ultracapacitor to capture a limited amount of regenerative braking energy). An exciting "mild hybrid" development that has not yet been commercialized is the 48-volt system. It could deliver much of the fuel savings of a full hybrid at a lower cost to the manufacturer and consumer (German 2015). Innovation in mild hybrid systems appears to be a priority in the industry (Sedgwick 2016).

Overall, the midterm reviews should carefully explore consumer reactions to the conventional hybrid, as that response is directly relevant to how consumers value fuel economy in real-world choices (German 2015). HEVs should also be considered as to whether they can serve as an effective bridge to PEVs. However, the presence of the ZEV mandate may deter investments in HEVs since CARB has determined that HEVs no longer contribute to compliance with the ZEV mandate. EPA is offering some near-term compliance incentives for hybrid trucks, but CARB is discouraging hybrid trucks in its ZEV program. Innovation in mild hybrid systems, including consumer reactions to them, should be tracked carefully.

4.65 Ethanol Blending

Almost thirty years ago, EPA began to require that refiners blend ethanol with gasoline to reduce U.S. dependence on oil and boost the octane content of gasoline. Environmentally, ethanol was seen as preferable for local air quality because the blend leads to fewer carbon monoxide emissions and smog-forming pollutants than 100% gasoline. The transition from 0% to 10% ethanol—favored by policies of both the Bush and the Obama administrations—was implemented by a rapid increase in production of corn-based ethanol (Graham 2010; 2016).

Corn-based ethanol, although renewable, became a target of criticism because the resulting increase in corn prices triggered protests in the U.S. and abroad, and the clearing of vast amounts of land for ethanol production was seen as environmentally undesirable (Hayes et al. 2009). EPA regulations have been changed to cap the growth of corn-based ethanol but instead compel increased use of advanced cellulosic ethanol that is made from corn stover, switchgrass, or various waste products (Harder 2016). The commercial viability of cellulosic ethanol remains uncertain but demonstration projects are underway (Bomgardner 2016).

From a consumer perspective, ethanol blending has a downside because ethanol has less energy content than gasoline, which means that a car will go fewer miles on the blend than on 100% gasoline (DOE 2017b). Ethanol is also more expensive to produce than gasoline. Nonetheless, the use of "E10" (a 10% blend of ethanol) has become widespread in the U.S. and, in some Midwestern states where ethanol is popular, significant quantities of E85 are being sold. In order to run on E85, an adjustment to the vehicle's fuel system is needed in order to prevent corrosion and damage to the vehicle's emission control system.

For many years the NHTSA CAFE program and the EPA GHG program offered generous compliance credits—also called "flex-fuel credits" (FFV)—to vehicle manufacturers that designed fuel systems that could accommodate varying blends of gasoline and ethanol. Those credits are being phased out by the federal government, which is consistent with the decision of the U.S. Congress not to renew tax credits and certain subsidies for ethanol. As FFV credits are phased out, vehicle manufacturers will need to find new ways to enhance CAFE and GHG compliance values, since the ethanol credits were used widely in the industry. In 2014, for example, the average vehicle manufacturer subtracted 9 grams of CO_2 per mile from its compliance value due to the availability of FFV credits (EPA 2016c).

4.66 Plug-In Electric Vehicles

Plug-in electric vehicles (PEVs) come in two general forms: the plug-in hybrid electric vehicle (PHEV) and the battery-electric vehicle (BEV). Large-scale studies show that a BEV with 75-100 miles of driving range is adequate to meet the energy requirements of 87% of vehicle days in the U.S. (Needell et al. 2016). The PHEV is more versatile because its driving range is typically as good as or better than a gasoline-powered vehicle. A 2016 survey of 1,052 U.S. adults suggested that two thirds of respondents are confused about the difference between a BEV and a PHEV (J. White 2016).

Compared to a gasoline vehicle of similar size, a BEV has several attractive features: electricity is generally a less expensive source of energy than gasoline; fewer maintenance costs such as oil changes; less interior noise and vibration from the powertrain; often better acceleration at lower speeds; the convenience of recharging at home; and zero tailpipe emissions. The tradeoffs for the consumer, however, can be significant: a higher initial cost due to the expensive lithium ion battery pack; uncertain battery longevity; restricted driving range (typically 75-100 miles, though ranges are improving); and long recharging times (3-4 hours if a Level 2 charging station is available).

The PHEV can be seen as a compromise between the conventional HEV, which cannot be plugged into the electrical grid, and the BEV. The big advantage of the PHEV is that the vehicle's driving range is superior to the BEV. Since PHEVs vary enormously in their electric-only range, they also vary in how much gasoline they save and in how clean they are.

In 2016, about 159,139 PEVs were sold in the U.S., about 0.9% of the 17.5 million new vehicles sold, as shown in Table 4.3 (Cole 2017). The PEV penetration rate is much larger in California (about 3%) than in most other states. The current market distribution of BEVs vs PHEVs is about 50-50, with Tesla's products dominating the BEV market and the Chevrolet Volt the best-selling PHEV. Consumers who decide against purchasing a PEV often express uncertainty with regard to their confidence in these vehicles' reliability and durability (Sierzchula et al. 2014; NRC 2015a). The key challenge for PEVs in the U.S. market is to move beyond the "early adopters" into the mainstream retail market for new vehicles.

4.67 Hydrogen Fuel Cell Vehicles

Several vehicle manufacturers (especially Toyota, Honda, Hyundai and General Motors) believe that a hydrogen fuel cell vehicle (FCV) could have greater long-term promise than a BEV. The FCV has no tailpipe emissions, no serious range limitations, and no performance disadvantages. It can be refueled by consumers in the same way that consumers refuel a gasoline-powered vehicle. The tradeoffs are initial cost (still much larger than a BEV), the need for a source of clean energy to produce the hydrogen, and the need for a network of hydrogen refueling stations. A large amount of space is required for the hydrogen fuel tank, which could compromise trunk space or interior volume, but some BEVs—due the large size of battery packs—have a similar problem. Progress in R&D

Table 4.3. U.S. PEV Sales: Number of Offerings, Total Sales, and Average Sales per Offering

Year	Number of PEV Models	Total PEV Sales	Average Sales per Model
2010-2011	3	17,425	5,808
2012	9	52,607	5,845
2013	16	97,507	6,094
2014	22	122,438	5,565
2015	28	116,099	4,146
2016	32	159,139	4,973

Source: Inside EVs. Monthly Plug-In Sales Scorecard; http://insideevs.com/monthly-plug-in-sales-scorecard/

is rapidly reducing the cost of producing FCVs and making them more appealing for consumers (Schoettle and Sivak 2016), but, for the foreseeable future, FCVs appear to be a less cost-effective approach to carbon control than PEVs (Felgenhauer et al. 2016).

Toyota, Hyundai, and Honda are, or once were, selling a limited number of FCVs in California. FCVs qualify as ZEVs and earn bonus compliance credits under the ZEV program. The State of California, in partnership with vehicle manufacturers, is using public money to establish a limited number of hydrogen refueling stations. Nonetheless, it is much too early to gauge how difficult it will be to sell FCVs to large numbers of consumers.

4.7 Special Behavioral Challenges Posed by AFVs

Switching to a fuel other than gasoline is appealing to many consumers, but there are several barriers to the deployment of any alternative fuel vehicle (AFV). Those barriers relate to lack of consumer awareness, misperceptions, cost, and inadequate refueling infrastructure.

A 2016 Harris survey commissioned by Ford (N=1,052 U.S. residents) found that 67% of respondents do not know anyone who has owned a hybrid, BEV or PHEV. Three-quarters of respondents were "not at all sure" about the maximum driving range of a PHEV on a single charge. Their guesses wildly underestimated the ranges of PHEVs, suggesting that respondents may have confusion about how PHEVs differ from BEVs (LeSage 2016).

For PEVs, the challenge of moving beyond the early adopter to the mainstream consumer is substantial. A September 2016 survey of U.S. adults (N=542) found that almost 80% of respondents reported "no prior experience" with PEVs (Schoettle and Sivak 2016). A recent review of surveys concluded that PEV awareness levels are low: a majority of adults cannot name a single PEV (Plug In America 2016). Even in California, where there has been substantial governmental promotion of PEVs, a 2016 survey found that a majority of consumers in the state have not yet made a decision as to whether they are interested in a PEV (Kurani, Caperello, and TyreeHageman 2016).

NRC (2015b) identified barriers specific to the adoption of PEVs. These include "limited variety and availability of PEVs; misunderstandings concerning range of PEVs; difficulties in understanding electricity consumption, calculating fuel costs, and determining charging infrastructure needs; complexities of installing home charging; difficulties in determining the 'greenness' of the vehicle; lack of information on incentives; and lack of knowledge of unique PEV benefits." Many other studies confirm these findings (Carley et al. 2013; Krause et al. 2013; Plug In America 2016).

Moreover, consumers are wary of new, unproven technologies. Some consumers might reason: I will let other people experiment with this technology before I take the gamble. In the face of risk and uncertainty, consumers will often turn to the familiar choice: a vehicle with an internal combustion engine (Egbue and Long 2012; NRC 2015a; NRC 2015b; Siddiki et al. 2015).

One of the big uncertainties is the availability of fuel. In much of the country, fuel infrastructure is underdeveloped for electricity, hydrogen, compressed natural gas, and even diesel in some areas. As more AFVs are sold, more fueling stations are added, and gasoline prices rise, demand for these vehicles should rise accordingly. However, consumer demand may not rise quickly enough to allow manufacturers to meet the federal and ZEV standards set for 2022-2025. In addition, the costs of AFVs are typically higher than that of conventional vehicles. Although consumers might see net savings over many years of ownership, current fuel prices are too low to generate large near-term benefits (Frades, Nigro, and Fazeli 2015).

The perceived value of a BEV will not be the same for all consumers. The real or anticipated travel behavior of the consumer can serve as a primary reason for a consumer's decision not to purchase a BEV. The average household takes approximately three trips and drives approximately 30 miles per vehicle per day, resulting in an average trip length of less than ten miles (FHWA 2011). These trips consist of about 71% of all trips and 25% of all vehicle miles traveled. A more in-depth study found that the energy-requirements of 87% of vehicle days in major U.S. cities could be met by existing, affordable short-range PEVs (Needell et al. 2016).

Consumers also care about the less frequent, long-distance, high-energy trips. For instance, although long trips (of more than 100 miles) represent less than 1% of total trips taken (and 16% of vehicle miles traveled), a consumer's desire to have the freedom to take these trips may dissuade them from purchasing limited-range BEVs (NRC 2015b). Even if affordable 200-mile PEVs are offered, and recharging is widely available, owners may still require supplemental mobility services such as car sharing or a second vehicle for the highest-energy trips (Needell et al. 2016). This concern is especially weighty if a consumer anticipates that he or she will take several trips of long length each year. Additionally, the PHEV, with its ample driving range, may be more appealing than a BEV to the many buyers who seek a vehicle that can accomplish both long and short trips without refueling (Graham et al. 2014).

Studies are only beginning to sort out which demographic subgroups are more and less inclined toward specific AFVs. Helveston et al. (2015) found that older, wealthier, and more educated consumers—especially those who own multiple vehicles and have children in the household—are less sensitive to upfront and operating costs. Higher income consumers are also less interested in HEVs or PEVs. Consumers with lower incomes demonstrate more receptivity toward PEVs but, since PEVs tend to be expensive, lower-income households typically cannot afford them. Therefore, current purchasers of PEVs are on average more educated and have substantially greater incomes than purchasers of conventional vehicles (NRC 2015b).

In accordance with these findings, the states with the strongest PEV markets are those with high environmental consciousness, incentives in place for purchasing and owning these vehicles, and mandates for cutting carbon emissions (NRC 2015b). Nonetheless, even when financial incentives are available, consumers have been shown to be largely unaware of them. Krause et al. (2013), studied adult drivers in 21 large U.S. cities and found that 75% of respondents underestimated the value and advantages of PEVs, and 94.5% of respondents had no knowledge of state and local incentives for the purchase and use of these vehicles. On the other hand, Krause et al. (2013) found that consumers underestimate the price of a PEV. Many consumers may not fully value PEVs unless they are provided information on the monthly total cost of ownership of these vehicles, compared to an otherwise similar gasoline vehicle; current vehicle labels, however, do not provide this level of detail to potential car buyers (Dumortier et al. 2015).

Improved education about current incentives, and the potential U.S. application of other PEV incentives used around the world (Lane et al. 2013), could drive the market for these vehicles forward. However, it is not clear which public organizations have the responsibility and resources to undertake such a large-scale public education effort. CARB, EPA, and NHTSA are primarily regulatory bodies, with limited track records in public education. The Department of Energy (DOE) has strong technical programs, but much less experience in the social science aspects of promoting alternative fuel vehicles. DOE's Clean Cities program of AFV promotion is a coalition-based activity in over 100 cities but it lacks a strong research program in economics and the behavioral and social sciences. A priority for the midterm reviews should be a resolution about the responsibility for public education and research in this field.

Despite all of these barriers, PEVs have been experiencing relatively rapid commercialization—a more rapid rate of growth than that seen when HEVs were first introduced (see Table 4.4). Specifically, sales of PEVs in the U.S. grew at more than twice the rate of that of HEVs when comparing their first 34 months of sales (Graham et al. 2014).

Government subsidies and tax credits, coupled with relatively high gasoline prices, spurred much of the early growth in sales of PEVs. HEVs were eligible for only a small federal income tax deduction during the early years of Prius marketing. It was not until 2005 that Congress authorized a federal tax credit for the Prius (and other HEVs). Its maximum value ($3,400) was less than a half the $7,500 Congress authorized for PEVs in 2009. And it took several years for the Prius to acquire access to the HOV lanes in California and other states. Whether the next decade will see such favorable tax and HOV-lane treatment of PEVs in the U.S. seems increasingly uncertain.

Table 4.4. Recent Decisions by Selected High-Volume Vehicle Manufacturers to Offer PEVs

- Nissan is offering the 2017 Leaf, a BEV with 107 miles of range on a single charge, and has announced plans to offer a new low-cost BEV within two years (Cuthbertson, 2016).
- In addition to the Chevrolet Volt, a PHEV with 53 miles of all-electric range, GM is offering the new 2017 Chevrolet Bolt EV, a BEV, with 238 miles of range on a single charge (Team 2016).
- In addition to its 2017 i3, a BEV sedan with an optional gasoline range extender, and its 2017 i8 PHEV, BMW has announced plans to develop electric versions of its Mini, BMW 3 Series, and X4 SUV models (Reuters, 2016).
- Ford has announced plans to offer 13 PEVs and HEVs by 2020 in addition to an updated version of the Ford Focus Electric with new fast-charging capability (Naughton 2016).
- Volkswagen has announced global plans to boost the number of BEVs and PHEVs offered to 20 models by 2020 (Hetzner 2016; Boston 2016).
- Daimler has announced plans to bring more than six PEV models to the US market between 2018 and 2024 (Taylor and Sheahan 2016).
- Hyundai/Kia has announced plans to offer eight PHEVs and two BEVs by 2020 (Mims, 2016).
- Toyota is offering the 2017 Toyota Prius Prime, a PHEV, and has announced plans to offer one or more BEVs by 2020 (Schmitt, 2016).
- Honda has announced plans to offer the Clarity hatchback as a BEV and PHEV in 2017 as well as longterm plans to expand offerings of electrified vehicles (Kubota, 2016).

4.8 Consumer Valuation of Economy

4.81 The "Early Adopters"

A small percentage of "early adopters" care deeply about fuel economy and environmental protection (Helveston et al. 2015; NRC 2015a; 2015b). The size of the potential early-adopter population is a key statistic for fuel economy innovators but there is no consensus on precisely how small is small.

One method is to quantify the number of consumers who identify fuel economy as the most important factor in determining which new vehicle to purchase. According to the 2013 survey of the National Automobile Dealers Association (NADA) (at a time of relatively high fuel prices), 14% of respondents chose fuel economy as the most important factor (second only to "quality and dependability"). NADA finds somewhat greater interest in fuel economy among car buyers than among SUV/truck buyers (NADA 2015). Nonetheless, even consumers who value fuel economy highly do so in the context of a variety of attributes that they care about; and consumers who say fuel economy is a top concern do not necessarily purchase fuel-efficient vehicles (NRC 2015a).

The early adopters of PEVs in the U.S. and abroad have followed a familiar pattern in the auto sector. PEV buyers tend to be young, male, highly educated, live in urban areas, have high incomes, are technologically sophisticated or wish to make a pro-environment statement, are likely to have been an early adopter of the Prius, and often own multiple vehicles (NRC 2015a; Figenbaum et al. 2015).

Overall the purchasers of PEVs and HEVs have higher incomes than purchasers of new gasoline-powered vehicles. Recent U.S. data on the median household incomes of new car buyers ranged from $128,000-$148,000 for PEV buyers, $90,204 for HEV buyers, and $83,000 for buyers of gasoline vehicles (NRC 2015b). Median household income in the U.S. is just over $50,000 (U.S. Census Bureau 2015).

In 2016, a year of record total vehicle sales and PEV sales in the U.S. (see Table 4.3), it is revealing that high-end models are driving the upward sales trend: the Tesla Model S and X and the BMW i3. The more affordable PEV models (e.g., the Nissan Leaf and the Chevrolet Volt) are not keeping pace in sales volume (Woodyard 2016b; von Kaenel 2016). In other words, PEV sales are largely confined to the "early adopter" segment, with only limited penetration of the mainstream retail vehicle market.

In order to move beyond the early adopters, PEVs must have a compelling and tangible value proposition. For example, in California, where the market is moving beyond early adopters, the most frequent motivation for purchasing a PEV is to "save money on gasoline or diesel fuel" (Kurani, Caperello, and TyreeHageman 2016). The same study found that health hazards of local air pollution are also a key motivator in California but that sentiment may not be as strong in other states.

The temporary, unexpected decline in PEV sales in 2015 has been attributed to falling fuel prices but there is an alternative interpretation. Many upscale consumers may have been aware that a variety of new PEV offerings were scheduled for release in 2016, and thus they delayed their purchase (von Kaenel 2016).

What is clear is that the rate of growth in total PEV sales seems to be slowing in the U.S., despite a growing number of plug-in models for consumers to choose from (see Table 4.3). A possible explanation is that the population of early PEV adopters is nearing exhaustion, at least in those cities that have made the necessary start-up investments in public education and recharging infrastructure. Alternatively, it is possible that many early adopters are waiting for the arrival of new PEV models (e.g., Tesla's Model 3 or GM's Chevrolet Bolt). More growth in early-adopter sales should be expected as battery prices decline, the driving range of BEVs is lengthened, and more states and cities become ready for PEVs.

4.82 The Rational-Choice Buyer

From a rational-choice perspective, the new vehicle consumer will purchase a new vehicle with superior fuel-saving technology if, other things equal, the present value of the stream of fuel savings is greater than the upfront cost of the technology. As summarized by NRC (2015a, 312), federal regulators argued in 2012 that the 2025 standards are a good investment for consumers. While the 2025 CAFE standard was estimated to increase the average price of a new vehicle by about $1,800 (relative to the 2016 standard), the consumer was estimated to save $5,700 or $7,400 over the long lifetime of the vehicle (up to 30 years for cars, 37 years for light trucks), depending on whether a 3% or 7% annual discount rate is applied to future fuel savings (NHTSA 2012a). The investment appears to be so attractive that the 2025 standards might increase vehicle sales if consumers are aware of the large fuel savings and do not undervalue them (NRC 2015a, 312).

The above assertion, by itself, can be questioned because the vehicle-sales impacts of regulatory standards depend on affordability issues and on how consumers actually perceive and value fuel savings in the automotive market. With respect to affordability, many consumers have an upper limit on what they can pay for a new vehicle, a limit that is defined by how much they can borrow and how large of a car payment they can manage and get approved. If a costly new fuel-saving technology is mandated, consumers may need to delay their purchase, shift to the used-car market (where prices are lower), or forgo other features or options that they desire (e.g., downsize, or give up 4-wheel drive, or compromise on trim level or engine size). Fuel savings later in the life of the vehicle do not change the basic affordability issues for consumers that face a binding budget constraint in the short term.

If the fuel-saving technology is affordable, then there is the question of whether the perceived fuel savings, in the eyes of the consumer, are worth the price premium for the technology. Resolution of this question must account for a variety of real-world complications and insights from behavioral economics, in addition to the predictions of rational-choice theory. We consider here several real-world behavioral complications: (1) fuel-price expectations, (2) consumer time horizon on fuel savings (or the related concepts of time preference or discount rate), (3) perceived resale value of the vehicle, and (4) consumer valuation of non-monetary attributes of vehicles.

EPA analysts make a plausible defense of the above comparison by describing it as a measure of "experienced utility" (a prediction of consumer well-being after the regulation takes effect and the consumer experiences their fuel-efficient vehicle) rather than "decision utility" (how consumers perceive their well-being will be impacted at the time of vehicle purchase). Fischer et al. (2007) suggest it is possible for a regulation to make consumers better off over time than consumers thought they would be without a regulation or prior to adoption of the regulation (Helfand and Dorsey-Palmateer 2015). For our purposes, where impacts on new vehicle sales are based on a key behavioral variable, it is the "decision utility" approach that seems more appropriate since it simulates the choice of the consumer when the purchase decision is made.

4.821 Fuel-Price Expectations

The fuel-savings estimates of $5,700 or $7,400 are based on official EIA forecasts of gradually rising gasoline prices over the life of the vehicle. A consumer's perception of future fuel prices may deviate from the forecasts of federal agencies. Recent evidence suggests that consumers, when making purchasing decisions, do not forecast—as EIA does—that fuel prices will rise gradually after the vehicle is purchased. Instead, consumer beliefs about future fuel prices, absent any recent price shocks, are similar to a no-change forecast (Anderson, Kellogg, and Sallee 2013; Anderson, Kellogg, et al. 2011). In other words, from the perspective of consumers, the fuel prices observed in the months prior to their purchasing decision are assumed to persist for the foreseeable future, a phenomenon that we explore in depth in our own modeling work in section 8.

4.822 Consumer Time Preferences about Fuel Savings

When consumers purchase a new vehicle, they do not plan on keeping the vehicle for its entire lifetime. The average vehicle lifetime is 14 years and rising, while the maximum lifetime is 30 years for cars and 37 years for trucks. A majority of consumers own the vehicle for less than seven years, many for only three or four years, and then trade it in for a new vehicle or sell it in the used-car market (NRC 2015a; CAR 2011). Consequently, we need to understand how new-vehicle consumers value fuel savings during their anticipated period of vehicle ownership and how, if at all, they consider the resale value fuel economy technology in their original purchasing decision.

Practical experience with fuel-saving technologies over several decades has cast doubt on the notion that new vehicle purchasers are strongly interested in fuel economy. In the 1970s, after the Arab oil embargo, Chrysler had only limited commercial success with the Plymouth Feather Duster and Dodge Dart Lite (rated the most fuel-efficient small car). From 1990-2005, Honda consistently offered more fuel-efficient technology than any other major automaker (e.g., the Variable Valve Timing and Lift Electronic Control (VTEC) system). Indeed, Honda's hybrid Insight was offered in the U.S. slightly ahead of the Toyota Prius. However, according to one industry expert, the company was not rewarded with appreciable gains in sales relative to other automakers, and thus Honda chose to relinquish its role as U.S. industry leader in fuel economy, though it remains a fuel economy leader in many countries where fuel prices are high (German 2016b).

4.8221 Insights from Consumer Decisions about Conventional Hybrids

In response to rising fuel prices from 1990-2007, more automakers made efforts to sell fuel economy. Toyota led with the first successful hybrid car, the Prius, which (boosted by HOV lane access and federal and state tax credits) became the largest selling car in California in 2012 and 2013. The buyers of the Prius extended well beyond the "early adopter" population and included financially-oriented buyers (Klein 2007). The Prius success has not been easy to replicate by Toyota or other automakers.

Ford Motor Company licensed technology from Toyota to offer its precedent-setting hybrid SUV, a hybrid version of the popular Ford Escape SUV (Berman 2011). After almost a decade of sluggish commercial experience, Ford discontinued the Escape Hybrid in 2012 and pursued a different approach to fuel economy enhancement. See our case study of the Ford Escape Hybrid on pp.38-39.

In 2016, there were 29 conventional hybrids offered for sale in the U.S. in different vehicle classes where a comparator gasoline vehicle could be identified. Hybrids typically had a significant price premium ($5,322 on average) but offered sizeable (undiscounted) fuel savings to the purchaser over the life of the vehicle (Vincentric 2016). After five years of use, six of the 29 vehicle offerings had fuel savings that exceeded the hybrid's price premium; after 10 years of ownership, almost half (14 of 29) offered fuel savings greater than the price premium.

Previous versions of the same study (Vincentric 2014; 2015) found that, when fuel prices were higher (almost $4/gallon), a much larger percentage of the hybrids offered net consumer savings over five or ten years of ownership. However, only the Toyota Prius has achieved high sales volume in the marketplace. A reviewer of the 2014 study of hybrids, citing the low national rate of hybrid sales, noted that "the fuel savings were not large enough to motivate most consumers to pay for the incremental cost" (German 2015).

When new car shoppers asked questions from 2005-2015 about the financial case for a hybrid purchase, consumer-facing experts in the industry would typically respond that the payback period (using undiscounted fuel savings) is longer than three to five years but shorter than 10 years for most hybrid models (Ransom 2008; Krebs 2012). Notice that the refinements to the gasoline engine stimulated by the federal standards have shorter payback periods while PEVs have longer payback periods than the conventional hybrids.

As a result of decades of real-world experience with fuel-saving technologies, practitioners are in broad agreement that most new vehicle consumers tend to be somewhat impatient about fuel savings. NRC (2015a, 315), in its information-gathering process, "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." Repeated national surveys, which make use of the stated preference method of consumer valuation, also suggest that consumers focus primarily on fuel savings accrued during the three years after purchase (Greene, Evans, and Hiestand 2013).

As a result, the typical approach of analysts has been to include only a few years of fuel savings and/or apply a high real rate of discount to future fuel savings. For example, Small (2010) described "consumer myopia" as "the predominant view," and captured it in his model by considering only three years of fuel savings coupled with a 15% annual discount rate on those savings.

4.8222 Insights from the "Energy-Efficiency Gap" Literature

The growing academic literature on energy economics sheds further light on consumer valuation issues and has challenged some of the conventional wisdom in the auto industry. The literature uses the term "energy efficiency gap" to describe the situation where consumers and/or firms fail to adopt energy saving technology, despite the fact that doing so would lower energy expenditures by more than the cost of adopting the energy-efficient technology (Greene 2010). From an econometric perspective, the phenomenon of an "energy gap" or "consumer undervaluation" is difficult to distinguish from a setting where consumers with different preferences about fuel economy are sorting themselves into different types of vehicles (Bento, Li, and Roth 2012). Nonetheless, Allcott and Greenstone (2012) and Greene and Welch (2016) identify two main strands of the empirical literature on autos that have attempted to determine the existence of the energy gap.

The first strand, which covers engineering-economic studies, estimates the net present value of a set of possible energy efficient investments. This strand generally finds evidence of a substantial efficiency gap (Rosenfeld et al. 1993; Greene, German, and Delucchi 2008; Granade et al. 2009; Greene 2011). NRC (2015a) provides a useful summary of this literature as it applies to automobile fuel economy, and concludes that there is a good deal of evidence to support the gap. This line of evidence is generally consistent with validated concepts in psychology, decision theory, and behavioral economics such as consumer bias for the present (sometimes called "present bias"), inattention, and risk aversion toward new technologies (Allcott and Greenstone 2012; Greene and Welch 2016).

The second strand of evidence, based on econometric analyses of large market data sets, advances the hypothesis that changes in the fuel cost of a vehicle are capitalized in the vehicle's market price. Therefore, the energy gap exists if, relative to a fuel inefficient vehicle, the increase in market price of a fuel-efficient vehicle is less than the increase in the present discounted value of fuel costs. The evidence from this strand of the literature favors the conclusion that the gap either does not exist or is modest in magnitude (Busse, Knittel, and Zettelmeyer 2013; Allcott 2013; Allcott and Wozny 2014; Sallee, West, and Fan 2016).

The study by Busse et al. (2013) is particularly notable because it challenges the widespread view that consumers are "myopic" about fuel economy. The data are a 20% sample of all U.S. 1999-2008 vehicle transactions. They show the effect of short-term changes in gasoline prices on short-run equilibrium prices of vehicles. They also show that market shares of vehicles with different fuel economies are sensitive to changes in fuel prices. For both new and used vehicles, they show that fuel-efficient vehicles command higher prices when fuel prices are high than when fuel prices are low. In many of their simulations, the implicit consumer discount rates on future fuel savings are relatively low, near or below the real rates of interest on car loans. They "find very little evidence of consumer myopia" (Busse, Knittel, and Zettelmeyer 2013, 253).

Allcott and Wozny (2014) use short-term variation in fuel prices from 1999-2008 to examine consumer interest in fuel economy as revealed by 45 million used-car transactions at auctions. The Kelley Blue Book and other retail price guides are typically based on auction prices. The vehicles are ages 1-15 years old. Like Busse et al. (2013), Allcott and Wozny (2014) find that used-vehicle prices are sensitive to short-term changes in fuel prices. However, they find some evidence of consumer undervaluation; consumers value only 55% or 76% of future fuel savings, depending on how consumers are assumed to forecast future fuel prices. Allcott and Wozny (2014) find relatively little consumer undervaluation of fuel savings in the early years of a vehicle's life; undervaluation is concentrated later in the average vehicle's 15-year lifetime.

The results reported by Busse et al. (2013) and Allcott and Wozny (2014) are not necessarily inconsistent. Allcott and Wozny (2014) note that the implicit discount rates reported by Busse et al. (2013) are actually quite variable, ranging from -6.2% to +20.9%. When the assumptions in Busse et al. (2013) were aligned with the assumptions in Allcott and Wozny (2014, 782), the implicit discount rate was +13%, which is considerably larger than the typical 6-7% real interest rate on car loans applicable to the relevant study period. However, the implicit discount rate in Allcott and Wozny (2014) that is most consistent with a flat fuel price forecast and full valuation of fuel savings is 24% (Allcott and Wozny 2014, 790). Because this discount rate is substantially higher than the historical average auto-loan rate of 7%, this may be taken as evidence of undervaluation. In our own modeling in section 9, we make use of the 55% valuation estimate but we also report alternative results for 100% consumer valuation—the position favored by Busse et al. (2013) and Sallee, West, and Fan (2016).

The above studies, though based on a rich body of information about real-world consumer decisions, are of questionable relevance to assessing how new-vehicle consumers would evaluate innovative fuel-saving technologies stimulated by regulation. For instance, most of the data are drawn from the used-vehicle market. Only two of the studies (Busse, Knittel, and Zettelmeyer 2013; Allcott and Wozny 2014) contained data on new vehicles, and Allcott and Wozny did not analyze the new car data separately. It is well known that consumers of used vehicles are different from consumers of new vehicles, and it is not obvious how to adjust the findings from the used-car market for use in the new vehicle market.

Moreover, the recent studies draw their inferences from short-term movements in fuel prices. Behavioral scientists have speculated that consumers may be particularly sensitive to near-term changes in fuel prices, since consumers pump their own gas and watch price and expenditures as they do so (Ariely 2008). The consumer's short-term response to higher prices at the pump may be different from their long-term response as the consumer becomes accustomed to higher prices and modifies their original (over)reaction (Greene and Welch 2016).

Most importantly, all of this recent evidence drawn from fuel-price changes does not directly study consumer responses to new fuel-saving technologies mandated by regulation. For example, fuel-price changes often motivate consumers to choose a different size class of vehicle and/or size of engine. Both of those choices are well known to affect fuel economy, but do not cause the same kinds of consumer uncertainty associated with purchasing a new fuel-saving technology or alternative-fueled vehicle. There is no doubt that consumer interest in AFVs is affected by changes in fuel prices but the econometric studies of fuel-price changes do not isolate the consumer's evaluation of new technologies. How a consumer values fuel economy due to a change in fuel price may not be the same as how that consumer values fuel economy due to unfamiliar new technologies. Consumer valuation is further impacted by uncertainties about potential fuel savings and the subtle effects on a vehicle's functionality or drivability due to new fuel-saving technologies.

Ideally analysts should study how consumers react to new fuel-saving technologies, since that is what the regulations stimulate, but this will be challenging. The growing body of real-world evidence of consumer reactions to hybrid offerings is arguably more directly relevant to the regulatory analysis questions faced by the federal agencies; it suggests that the typical consumer does not value a vehicle's entire lifetime of fuel savings at the time of original purchase. If the consumer did so, the rate of hybrid sales—which typically have payback periods less than the projected vehicle lifetime—would presumably have been much higher in the U.S. from 2000-2013, when fuel prices were high and rising (Vincentric 2016; 2014; 2015; Montoya 2014).

However, sluggish hybrid sales do not necessarily conflict with full valuation of fuel economy because the apparent energy efficiency gap may have other cogent explanations (Allcott and Greenstone 2012). For example, consumers may resist a new fuel-saving technology if the valued attributes of the vehicle may be compromised or if the consumer fears that they could be compromised. In fact, this possibly explains why the energy-economics literature explores the energy gap using changes in fuel price rather than changes in fuel-saving technology. It is very challenging to assess econometrically whether sluggish hybrid sales are due to undervaluation of fuel savings or concerns about the performance of hybrid vehicles (even if those concerns are unfounded). Some authors refer to such effects as "hidden amenity losses," since they are not reflected in the cost of the technology (Small 2010).

In short, consumers may be turned off by perceived compromises caused by new technology and therefore prefer to let other consumers try the innovation before spending money on what may be seen as a risky investment (NRC 2015a; NRC 2015b). We discuss the possible hidden losses below, after we consider the role of resale value in the market for fuel economy.

4.823 Resale Value of Vehicles

NHTSA (2012a) reported that the average residual value of a vehicle after five years of ownership was 35%; CARB (2011a) used a figure of 50%. Both values are undiscounted. Those agencies further assumed that new vehicle consumers make unbiased forecasts of these residual values, that the values are applicable to fuel-saving technology (as well as the vehicle as a whole), and that these values are unaffected by fuel price. As we explain below, these are strong assumptions that are not highly consistent with the literature on energy economics reviewed above.

A car with increased fuel economy will save consumers money throughout the entire vehicle lifetime. Since the average new vehicle consumer holds on to the vehicle for less than half of its useful lifetime, the resale value of a vehicle with new fuel-saving technology should be considered, at least from a rational-choice perspective. From a behavioral economics perspective, the role of resale value in the original consumer's choice of a new vehicle is uncertain and complicated.

Fuel economy may seem less salient to the used car buyer than to the new car buyer because the EPA fuel economy label, which supplies standardized MPG data for all new vehicles, is not available on used cars (Saulsbury et al. 2015; Austin and Dinan 2005). If the consumer is motivated to search, there are plenty of websites that supply information on the fuel economy and resale value of different makes and models (e.g., Kelley Blue Book, NADAguides.com, Edmunds.com, Fueleconomy.gov, and ALG). Nonetheless, the U.S. Department of Energy has launched an entire public education program to help used car buyers better understand fuel economy (Saulsbury et al. 2015).

In the used-car setting, there is a distinctive and crucial attribute—condition of the vehicle—that is of strong concern to the buyer. That focus may tend to reduce the significance of second-order attributes, such as fuel economy (German 2016b). Vehicle condition is obviously not an issue for the new vehicle purchaser.

Purchasers of used vehicles are more price constrained than new vehicle buyers, presumably because of differences in average income and assets. Their price sensitivity may make them particularly averse to the cost premium for a car with superior fuel economy technology. On the other hand, lower-income households spend a larger share of their after-tax income on gasoline than higher-income households (Greene and Welch 2016; Farrell and Greig 2015). Therefore, technology that decreases gasoline expenses may have special appeal to the lower-income, used car buyer.

Rational-choice theory also predicts that consumers will consider how the likely resale value of a vehicle is influenced by fuel prices. Other things equal, a vehicle with good fuel economy should command a higher price in the used-car market than a vehicle with poor fuel economy. Price data from used-vehicle auctions in 2008-9, when fuel prices were high, found a premium for vehicles with higher-than-average fuel economy, including hybrids and diesels (Gilmore and Lave 2013). Indeed, the econometric analyses reviewed above have shown that the price premium for a used vehicle with superior fuel economy is greater when fuel prices are high than when fuel prices are low (Busse, Knittel, and Zettelmeyer 2013; Allcott 2013; Allcott and Wozny 2014; Sallee, West, and Fan 2016). This insight needs to be incorporated into how NHTSA and EPA RIAs model consumer reactions to fuel-saving technology; our modeling in section 9 provides a starting point for the agencies.

There are consumer information problems related to depreciation rates and resale values. When a national sample of 1,004 Canadian drivers were asked what they think is the greatest monthly cost of owning a vehicle (from a menu of choices), responses were 33% insurance, 29% gas/fuel, 24% maintenance, 3% loan payments, and 9% other responses or don't know. Only 1% of respondents selected the correct answer: depreciation (Canadian Black Books 2016). New passenger vehicles lose about 11% of their value immediately after they are sold, and their value depreciates 15-25% per year for their first five years of age (Greene and Welch 2016). At the same time, assumptions about the annual rate of depreciation in comparative vehicle cost studies vary substantially. Sharma et al. (2012) use a constant rate of annual depreciation of 6%, Gass et al. (2014) assume a rate of 33% for EVs and 22.5% for diesel ICEs, while Al-Alawi and Bradley (2013) apply a rate of 13.8%, which is the historical rate of depreciation of the first generation Toyota Prius. If experts as well as consumers are uncertain about depreciation rates and resale values, one should not assume that new-vehicle consumers consider future resale value in a highly informed, rational manner.

The peer reviewed literature has, for the most part, failed to address the behavioral expectations of new-vehicle consumers on resale values. However, some constructive insights from recent surveys may be relevant here. About half of the respondents in the Canadian survey described above were planning to purchase a vehicle within the next 18 months. Many consumers consult information on resale values when they prepare to trade in their car or sell it in the used car market. New vehicle purchasers rarely do so, in part because historical data on resale values is limited and resale-value estimates may be unreliable for new models. Only 7% of consumers use online resale-value calculators when doing basic research on vehicle options; 60% do so when they are about to evaluate a trade in (Mertl 2016).

The new vehicle purchaser may see the resale decision as many years down the road, beyond the time horizon of their purchasing decision, especially since they may not know how long they will hold the vehicle. Indeed, insofar as the average new vehicle consumer is not inclined to consider fuel savings beyond three years after purchase, the question is whether that consumer would give much weight to the resale value of fuel-saving technology, since the first resale is typically at year six or seven of the initial ownership period (NRC 2015a). Some classes of new vehicle buyers seem likely to be sensitive to resale value issues: the buyer who regularly holds for only two to three years and resells, or the consumer who leases, since residual value is—at least implicitly—wrapped into the leasing deal. Consequently, the entire question of how much new-vehicle consumers consider resale value is uncertain and variable among the group.

We found no surveys that ranked resale value in the top 10 to 20 factors that influence new-vehicle consumers, though it is possible that other salient factors such as brand loyalty may be related to resale value. Resale value is certainly embedded in "overall value for the money" (which tends to rank high as a factor in consumer surveys) but that construct encompasses other important factors (vehicle price, durability, and reliability) that are known to be important. When "future trade-in or resale value" is included in such surveys, it tends to rank far below fuel economy. The fact that many surveys of new car buyers do not even include resale value as a possible decision factor reflects the view of industry experts that resale value does not make the cut as a top consideration for that group of consumers (German 2016b). Furthermore, resale value has been largely neglected by comparative vehicle cost analyses that cover different vehicle types. In a meta-analysis of 44 studies that conducted such a comparative analysis, only eight considered resale value or accounted for the residual value of the vehicle by assuming an annual depreciation rate (Roosen, Marneffe, and Vereeck 2015).

Consumers who have concerns about resale value at the time of original purchase may be less worried about a modest refinement to the gasoline engine (e.g., turbochargers or cylinder deactivation) than an entirely new powertrain or fuel in an AFV. In 2015, amidst low fuel prices, the annual depreciation rates for hybrids and plug-in vehicles ranged from 25-30%, about twice the average rate for gasoline-powered passenger vehicles (T. Healey 2016; Sawyers 2016). Some PEVs have very low resale value (Woodyard 2015). As an example, resale values for the Nissan LEAF fell from 43.5%, to 36.5%, to 25.3% in each of the first three years of the vehicle's life, respectively (NADA 2015). As fuel prices have declined, the residual values of plug-in hybrid vehicles, such as the Toyota Prius Two, also have fallen significantly (Sawyers 2016). Interestingly, Kelley Blue Book reported in 2016 that Tesla products are the only PEVs to hold their value well over a three-year ownership period (Woodyard 2016c).

In summary, it should not be assumed that new vehicle consumers are well informed or fully consider the future fuel-savings of new technology over the entire life of the vehicle. Nor should it be assumed that the resale value of new fuel-saving technology is unaffected by fuel price. A total cost-of-ownership model for fuel savings from new technology should incorporate insights from behavioral economics as well as actuarial evidence of the extent of fuel savings over a vehicle's lifetime. We have taken a step in this direction with our own modeling in section 9 and Appendix VIII.

4.824 Non-Monetary Attributes of Vehicles: Positive Intangibles and Hidden Amenity Costs

The possibility of non-monetary utility gains or losses from fuel-saving automotive technologies also needs to be examined. For example, advanced diesel engines tend to have greater torque, which assists in acceleration, towing, and hauling (NRC 2015a). Electric vehicles offer a quieter ride and some have performance advantages (NRC 2015b). However, some fuel-saving technologies have non-monetary drawbacks that may be missed in engineering cost studies (Roth 2014).

As regulators have imposed stricter fuel economy standards on automakers, industry surveys have found that the perceived quality of new vehicles has suffered, at least temporarily. Michelle Krebs of Edmunds.com has commented that "...automakers are tweaking their engines and transmissions to maximize fuel economy, but their experiments have taken their toll in terms of driving experience, and quality ratings are suffering as a result" (Woodyard and Maier 2011). On the other hand, federal agency analysts (TAR 2016) performed a content analysis of expert reviews of fuel-saving technologies in recent model passenger vehicles, specifically expert commentaries in consumer-facing publications. They found little evidence that fuel-saving technologies were associated with significant losses in other vehicle attributes that consumers desire (Helfand et al. 2016). In addition, the most recent J.D. Power's study of auto quality found that manufacturers are making "some of the highest quality products we've ever seen" (JD Power 2016).

Some consumer concerns have been raised about small turbocharged engines, dual-clutch transmissions (DCTs), and stop-start systems. Automakers have added turbochargers to smaller engines in order to boost fuel economy and performance. Consumers Union reports that some motorists who are unsatisfied with the acceleration capability of the turbocharged engine push down the pedal strongly, thereby dampening the fuel economy of the vehicle. Thus, consumers may be frustrated by either poor acceleration or less real-world fuel economy than was advertised by the vehicle manufacturer (Truett 2013). Over time, though, manufacturers have responded to consumer concerns and improved the performance of turbocharged engines (NRC 2015a).

A similar pattern occurred with DCTs. Early versions of DCTs triggered complaints related to drivability, especially among consumers accustomed to conventional automatic transmissions. New designs of DCTs are expected to have higher rates of consumer acceptance (NRC 2015a, 5–51).

Consumer reactions to stop/start systems, which reduce idling losses, have been variable. Toyota has successfully used stop/start technology in the Prius for more than a decade. Some stop/start systems annoy consumers due to noise and vibration during restarting; these consumers may be accustomed to smooth acceleration from a stop. European consumers have been more receptive to stop/start systems than American consumers (NRC 2015a). A variant of the stop/start system is the mild hybrid system, as implemented in the eAssist system of the Buick LaCrosse and Regal and earlier Chevrolet Malibu, which may achieve both larger gains in fuel economy and improved customer acceptance (NRC 2015a, 131). Indications from the industry are that stop/start systems, in various forms, will soon be widespread in the American market (Truett 2016b; Taub 2016; Sedgwick 2016).

Consumers may also notice it when new materials are used in a popular vehicle. All-aluminum pickup trucks save fuel but also have downsides that are unrelated to vehicle price. Aluminum is more prone to contamination than steel in the painting process, and consumers report more paint problems and corrosion with aluminum. Ford Motor Company is addressing such issues through new production processes and consumer advisories (Travers 2015).

For a completely new powertrain, such as a PEV, consumers may be averse to the worry and hassle (as well as the repair/replacement cost) associated with a battery pack that proves to have poor reliability and durability. The nickel batteries used in the Toyota Prius have proven to have excellent reliability and durability, often lasting well past the 100,000-mile warranty (up to 150,000 miles). Only about one to three percent of the nickel batteries in the Prius need to be replaced due to accidents or product failure, with failure events reported to be extremely rare (CEC 2015). It is too early to tell how well the lithium ion batteries used in PEVs will perform in the long run. Evidence of Nissan's concern about this issue is their battery warranty policy on the Leaf. The policy covers defects or sharp declines in battery capacity for eight years or 100,000 miles in higher-trim versions of the Leaf, but only five years and 60,000 miles in the base version (Woodyard 2016b).

Thus, the rate of new vehicle sales will also be influenced by factors other than the production cost and fuel savings of new technology. Analysts also need to consider carefully the impact of the technology on the non-monetary attributes of the vehicle that consumers value, everything from drivability to trunk space.

5. THE PRODUCER'S PERSPECTIVE

5.1 Industry Structure

The new passenger vehicle market in the U.S. is dominated by high-volume producers that sell globally: Toyota, Volkswagen, General Motors, Hyundai/Kia, Nissan-Renault, Ford, Fiat Chrysler, Honda, Suzuki, BMW, Daimler, Mazda, and Mitsubishi. Although the Big Three (Ford, GM, and Chrysler) were once the dominant three producers (indeed some economists still model the industry as an oligopoly), they have been gradually losing market share for decades and were downsized during the financial crisis of 2007-9 (Goolsbee and Krueger 2015). Today, the U.S. auto industry, defined here as companies selling vehicles in the U.S. (including their supply chains and dealers), is highly competitive, with strong Japanese, Korean, and German manufacturers competing against each other and against the Big Three (CAR 2015). Today, perfect competition may be a more accurate simplification than oligopoly (Helfand and Dorsey-Palmateer 2015).

Previous studies have found that the adverse financial impacts of stricter CAFE standards did not affect all high-volume producers equally. Historically, a disproportionate burden was felt by the Big Three, though this conclusion does not fully reflect the impact of the relatively new footprint-based structure of the CAFE and GHG standards (Sallee 2010; Jacobsen 2013). This new structure is designed to make the CAFE program binding on all high-volume vehicle manufacturers (Helfand and Dorsey-Palmateer 2015). EPA's GHG program has a similar design, which should trigger compliance investments at all high-volume vehicle manufacturers. The ZEV requirements are also expected to impact all major automakers.

Automakers vary considerably in their access to the technology and capital necessary to implement major changes in vehicle propulsion systems. Fiat Chrysler is carrying the largest debt load among the high-volume producers, and faces significant compliance challenges (Vellequette 2015). EPA (2016b) reports that Fiat Chrysler is more aggressive than other automakers in making use of the special compliance credits available in the EPA GHG program.

One of the possible reasons that Fiat Chrysler is publicly looking for a merger partner is that it may lack the capital necessary to make aggressive investments in response to both the federal and California regulatory requirements. Even if companies do not merge to address regulatory challenges, they may form alliances to share technological expertise. Toyota and Mazda are sharing information on advanced diesel and gasoline engines, while GM and Honda are sharing information on fuel-cell vehicles (Rocco 2015).

5.2 The Big Three and the United Auto Workers

The U.S. industry has both a unionized and nonunion sector. Organized by the United Auto Workers of America (UAW), the Big Three have business models that depend primarily on sales of light trucks assembled in the U.S. and Canada. Of the 64 models offered by the Big Three in model year 2017, about two thirds were assembled at UAW-organized plants (Stoll, 2016). About 75% of the passenger vehicles sold by the Big Three are trucks; the comparable figure for Japanese firms is about 50% (Bennett and Stoll 2015).

Domestic producers of light trucks are protected by an internationally-sanctioned 25% tariff on the importation of light trucks, though this tariff is under discussion in the ongoing trade negotiations between the EU and the U.S. (Beene 2015a; Young 2015). In recent years, Japanese and other foreign producers, which generally operate nonunion plants in the U.S., have begun to challenge the Big Three's dominance of the light-truck market. Toyota now builds the Tundra (pickup truck) at a nonunion plant in San Antonio, Texas, in order to serve the North American consumer market.

Toyota, Honda, and Nissan dominate the passenger-car market, but Hyundai/Kia, Volkswagen, and the Big Three are offering a mix of new and remodeled products that challenge Japanese dominance. Daimler, BMW, and Audi are major players in the U.S. market for upscale sedans and crossover vehicles; the latter being one of the most rapidly growing and profitable segments in the industry.

5.3 The Transplants

From 1950-1980, Japanese, Korean, and German automakers assembled their vehicles abroad and exported them to the U.S. for sale (Grossman 2009). To avoid unfavorable U.S. tariffs and currency valuations and to establish a credible presence in the U.S., those companies have increasingly located assembly plants in North America (Kurylko 2013).

The transplant share of U.S. auto production has steadily climbed from 22% in 2000 to 31% in 2005 and 46% in 2013; it is projected to exceed 50% by 2017 (Goolsbee and Krueger 2015; Kurylko 2013). Based on annual U.S. market shares, Toyota now rivals GM and Ford among the top three manufacturers selling vehicles in the U.S. market, and a majority of Toyota's U.S. sales are also assembled in the U.S.

The first "transplants" were located in Marysville, Ohio (Honda-1982), and Smyrna, Tennessee (Nissan-1983), but the largest plants today, in terms of vehicle production, are in Montgomery, Alabama (Hyundai-2005), San Antonio, Texas (Toyota-2006), Greenburg, Indiana (Honda-2008), Woodstock, Ontario (Toyota-2008), West Point, Georgia (Kia-2009), Blue Springs, Mississippi (Toyota-2011) and Chattanooga, Tennessee (Volkswagen-2011). Sometimes only the assembly of the vehicle occurs in the U.S. (e.g., to avoid a U.S. tariff on imported vehicles). For example, MercedesBenz used to assemble its Sprinter Van in Germany, disassemble it prior to shipment to South Carolina, reassemble it in South Carolina, and then sell the van in the U.S. market tariff-free. More recently, MercedesBenz has made a major commitment to a new production and paint facility in South Carolina (Henry 2016). As a result, the transplants are now major sources of local employment and fiscal stimulus in the U.S. economy.

5.4 Supply Chains and Parts

In order to appreciate the breadth of the industry and its workers, one must look beyond the assembly plants to the supply chains for engines, parts, batteries, and other components (MEMA 2013). GM, Ford, and Fiat Chrysler share a distinct network of suppliers often organized by the UAW (Goolsbee and Krueger 2015). When Ford publicly supported the rescue of GM and Chrysler in 2008-9, they did so because they shared a supplier base with GM and Chrysler. Had Chrysler and GM folded, the future of Ford would have been in question (Graham 2010).

The Big Three are diversifying their supplier base within North America while also importing more parts from outside the U.S. In model year 2010, 90% of the Ford Escape's content by value originated in the U.S.; in model year 2015, the domestic content of the Escape was only 55% (Hagerty and Bennett 2015). About half of the parts for the popular Ford Focus come from outside the U.S. and Canada, with about 20% from Mexico. Some of the Focus engines are from Spain; some of the Focus transmissions are from Germany.

The transplants vary enormously in how much business they have with U.S. engine and parts makers. Toyota is a large maker of its own engines and transmissions in the U.S. On the other hand, BMW assembles more than 200,000 luxury crossovers per year at a large facility in Spartanburg, South Carolina, but fewer than 10% of the parts come from the U.S. and Canada (Althaus and Rogers 2016).

The transplants assemble vehicles in North America but are even more likely to import the parts from overseas. Overall, importation of auto parts has grown from $31.7 billion in 1990 to $89 billion in 2008 and $138 billion in 2014 (Hagerty and Bennett 2015).

5.5 Mexico's Growing Role

Boosted by NAFTA, the role of Mexico in the North American auto industry is growing rapidly (Althaus and Rogers 2016). Both the Big Three and foreign automakers are locating an increasing share of their North

American production—especially small-car production—in Mexico, often in close proximity to the U.S. border. Nine of the last 10 new auto assembly plants announced for the NAFTA region are being built or have been built in Mexico (Wernle 2016).

The appeal of Mexico is multi-faceted: lower average wages ($6/hour), proximity to the many new assembly plants in the southern region of the U.S., and access to the global market through Mexico's free-trade agreements (Irwin 2016a; Wernle 2016). However, the supply chains for Mexican assembly plants often lead back to the U.S. In the average vehicle assembled in Mexico, 40% of the parts come from U.S. suppliers (Iliff 2016). Thus, the original equipment manufacturers and parts suppliers in Mexico, the U.S., and Canada are highly integrated.

5.6 The Startups, Silicon Valley, and China

The PEV could be considered a "disruptive technology" because it threatens to unseat the dominant technology: the internal combustion engine. Some disruptive technologies succeed; many others fail. A disruptive technology does not typically catch on until quality in mass production is established and widely recognized. Sometimes disruptive technologies remain a fringe offering for a long time; in other cases their pace of commercialization is astonishingly rapid (Christensen, Raynor, and McDonald 2015).

Several start-up producers of PEVs (e.g., Tesla, Atieva, Karma/Fisker Automotive, NextEV, Youxia, Lucid Air, and Faraday Future) are introducing even more competition into the U.S. and global auto industry (Ramsey 2015). Some of the recent start-ups have backing from Chinese companies and investors, reflecting the growing Chinese interest in PEVs (Lane et al. 2013; Millward 2015). The startups are part of a loose network of venture capitalists, suppliers of batteries and chargers, electric utilities, and environmental advocacy groups with a common goal: electrification of the transportation sector.

Major companies in Silicon Valley have also indicated an interest in offering new automotive components or entirely electric, driverless vehicles with the latest information technology (Boston 2015; Gibbs 2014). Many of the key companies and investors in the electrification network are based in California.

The California ZEV program was structured in a way that boosted the commercial fortunes of start-up EV makers. For example, Tesla, as a maker of BEVs, can sell ZEV compliance credits to large-volume vehicle manufacturers, such as Honda and Daimler, who may have near-term difficulty meeting their ZEV requirements (Webb 2010; Mulkern 2016). The federal programs are also designed to help PEV startups accumulate credits with market value. For example, the EPA program recognizes that PEVs produce emissions at the powerplant but, from model years 2012-2015, Tesla and other PEV producers were allowed to use a compliance value of 0 grams of CO2 per mile instead of the 103 grams of CO2 per mile that would account for some powerplant emissions (EPA 2016c). Tesla has reported profits in only two quarters since the company was launched, and in both of those quarters Tesla reported unusually large revenues from sales of regulatory credits (federal and ZEV program credits) (T. Higgins 2016).

In 2013, for example, each Model S that Tesla sold generated seven ZEV credits due to the vehicle's extended range and fast refueling capability. With the average credit selling for $5,000, Tesla earned $35,000 in extra revenue for each Model S sold (Knittel 2014). Even in years that Tesla reports losses, sales of ZEV credits have attenuated the annual financial losses. In 2014, Tesla was the largest seller of ZEV credits, earning $152 million or about 5% of the company's total 2014 revenue (S. Edelstein 2015). The role of the ZEV program in Tesla's commercial future illustrates a broader point: the dynamic structure of the U.S. auto industry is partly a reflection of the design of federal and state regulatory systems.

5.7 The Role of Dealers

The vast auto dealer network, with 710,000 employees at latest count, has national reach in order to maximize sales to consumers (CAR 2015). Vehicle manufacturers technically sell their products to dealers, who then have the responsibility of selling them to retail customers or fleet buyers. In contrast to Europe, where a large fraction of sales are made to companies or fleet buyers, the U.S. market is dominated by the unaffiliated retail buyer who strives to meet the transport needs of his or her household and often buys the car on credit.

In recent years, the role of the dealer as a source of information, though still important, has declined due to the explosion of user-friendly information on the Internet and extensive consumer use of social media. By the time consumers begin communicating with a dealer, many have already selected the vehicle that they wish to purchase. Thus, consumers have access to many more sources of information about vehicles than they did a generation ago.

The commercial experience of Tesla with direct marketing to consumers has also challenged the traditional dealer role (i.e., orders for Tesla products are placed online to the factory). In fact, while Nissan now sells the Leaf through dealers, it initially sold the Leaf only on the Internet (NRC 2015b). The National Automobile Dealers Association has challenged Tesla's marketing practices in several states—with mixed success—and defends franchise laws that require new vehicles (including PEVs) to be sold by trained, licensed dealers. Opponents of state franchise laws argue that such laws are outdated and do not serve the interests of consumers. The fact that dealers may have multiple operations representing more than one automaker complicates the task of examining the impacts dealers will experience from changes in vehicle sales.

A stronger focus on how dealers and manufacturers can collaborate to promote PEVs is warranted (NRC 2015b). So far, manufacturers are offering PEVs primarily as small cars and only in selected cities and states. Some large-volume manufacturers (e.g., Nissan and General Motors) have made major investments in dealer education and marketing while other manufacturers have done relatively little to promote PEVs. A study by UC Davis found that dealerships are not enthusiastic about selling PEVs because they require different marketing strategies as customers are not familiar with new technologies (Cahill and Sperling 2016).

There may actually be some disincentives for dealers to sell PEVs: the time and cost associated with training staff on new technology, educating staff on federal, state, and local PEV incentives, and developing a new capacity to service PEVs (Plug In America 2016). Some states have tried public recognition programs for dealers that excel at selling PEVs while others have offered dealers financial incentives or cash bonuses for each PEV sold. Those efforts need to be evaluated rigorously so that it becomes apparent what works best. Now that an enlarged number of high-volume manufacturers have made public commitments to offer PEVs, the dealer-customer interface regarding PEVs needs to be a priority for PEV promotion efforts.

5.8 The Economic Impact of the U.S. Auto Sector, Direct and Indirect

Considering all automakers, about 7 million U.S. jobs are supported, directly or indirectly, by the automotive industry. Each job in auto manufacturing is linked to roughly seven jobs in other industries throughout the economy (CAR 2015).

A different way to express the economic importance of the U.S. auto sector is to trace its impact on state and federal tax revenues. Hill et al. (2015) have done so, and place auto-related state tax revenue at $110 billion in 2013, or about 13% of total state tax revenue. A lower bound on auto-related federal tax revenue is $95.5 billion, or about 3.4% of total federal revenue.

The auto parts industry, which is the sector responsible for the largest share of manufacturing employment in the U.S. (935,900 in 2014), is not spread equally around the country (BLS 2015). A large majority (more than 70%) of auto parts manufacturing employment is concentrated in ten states: Michigan, Ohio, Indiana, Tennessee, Kentucky, Illinois, Alabama, Texas, North Carolina, and South Carolina (CAR 2015). When combined with the assembly plants, which tend to be located in these same states, it is readily apparent why the health of the auto industry is of greater concern in the South and Midwest than it is on the East and West coasts (Goolsbee and Krueger 2015).

Despite the widespread importation of auto parts, foreign auto brands contribute significantly to employment in the U.S. (Greimel 2015). In 2014, the production of Japanese auto brands contributed both directly and indirectly to 730,000 jobs in the U.S. The dealer network for Japanese brands contributed directly and indirectly to an additional 760,000 jobs in the U.S. The total associated employment was approximately 1.5 million. The net number of new jobs created in 2014, due to Japanese auto brands alone, was approximately 157,000 (Prusa 2015). Toyota alone has been shown to have significant impact on employment and tax revenues in 19 states (Dziczek, Chen, et al. 2016).

5.9 Public Subsidies and the U.S. Auto-Sector Recovery

Annual sales of new passenger vehicles—cars and light trucks—in the U.S. averaged 16 million from 1998-2007. Those sales collapsed to 10.4 million in 2009, reflecting the combined impact of accelerating underemployment, declining incomes, falling consumer confidence, defaults on home mortgages, and lack of consumer access to affordable car loans. The Bush and the Obama administrations took aggressive steps to rescue the U.S. auto industry from financial collapse (Graham 2010; Graham 2016).

Public subsidies and federal loan guarantees have played an important role in the recent resurgence of the Big Three, in the emergence of Tesla, and in Nissan-Renault's leading position on BEVs (Dolan and Murphy 2009). GM and Chrysler (including their financing arms and suppliers) emerged from structured bankruptcy proceedings in 2009 with financial backing from the U.S. Department of the Treasury (Goolsbee and Krueger 2015). In 2009-10, Ford Motor Company and Tesla received large federal loan guarantees from the DOE to develop and offer greener automotive technologies. Nissan also received a large DOE loan guarantee to build new facilities in Smyrna, Tennessee, to make lithium-ion battery packs and assemble BEVs.

The U.S. auto industry has been a heavily subsidized and regulated industry. A challenge for the future is to put manufacturers and suppliers in this industry on a level playing field for competition.

5.10 National Recovery from the Great Recession

Since 2009, the auto recovery has been significant. After six straight years of sales growth, the industry, boosted by low interest rates, in 2015 and 2016 was selling more than 17 million new passenger vehicles, an annualized record for the U.S. Virtually all of the high-volume automakers have been reporting increasing revenue and profit in the post-recession period. Although the profit margins for investments in the auto sector are less than in other sectors, the recent period of profitability has allowed the Big Three to offer multiple years of bonuses to their workers and to make some new plant investments in North America. Foreign automakers have also announced new plant investments in the U.S. In total, about $70 billion in company-announced investments in new, expanded, or retooled investments in North America were made from 2010-2014. About two-thirds of those investments are in the U.S. (CAR 2015).

As a result, auto-related employment in the U.S.—both at assembly plants and at facilities that make engines, components, and parts—has rebounded significantly. In September 2005, direct auto-related employment in the U.S. was measured at 1,089,800, falling sharply to a trough of 653,400 in September 2009. It has grown each year since 2009, and was recorded at 928,900 in October 2016 (BLS 2015).

The U.S. economic recovery from the Great Recession (2007-2009) has been painfully slow, indeed the slowest recovery on record, but one of the positive developments has been the revival of the U.S. auto industry (Seefeldt et al. 2013). The multi-year auto recovery accounted for 25% of the rise of manufacturing industrial production in the U.S. from 2009-2014, more than twice the average share in the four previous U.S. recoveries (Goolsbee and Krueger 2015). One estimate is that the auto recovery was related to about 10% of the overall recovery of U.S. GDP in 2014 (Young 2014).

5.11 Accelerated Retirement of Older Vehicles from the Fleet

While the federal standards and ZEV requirements focus on the design of new vehicles, most vehicles in use on a daily basis are not new. The U.S. passenger-vehicle fleet is comprised of more than 250 million vehicles, 57% cars and 43% light trucks (NHTSA 2009).

Changing the environmental profile of the existing fleet is a very slow process if the sole focus is the design of new vehicles. In a good year, only 17 million cars and light trucks are sold in the U.S. and new vehicles last longer today than they did a generation ago. Instead of the exclusive focus on new vehicles from 2022-2025, the midterm reviews may consider policies to accelerate the retirement of older vehicles from the fleet (Alberini et al. 2016).

So-called "cash for clunker" programs seek to accomplish this objective by offering cash incentives to consumers who agree to retire their old vehicle and replace it with a new vehicle. The result might be a higher rate of new vehicle sales as well as lower rates of gasoline consumption and GHG emissions. Side benefits of such policies may include enhanced safety for motorists, reduced emissions of pollutants related to smog and soot, and a tangible benefit for limited-income households that depend on older vehicles for their work and personal transportation. However, the evaluations of such programs, which we review in Appendix II, have been quite mixed. Therefore, policy makers who seek to achieve environmental results from cash-for-clunker programs need to make sure that they are carefully designed to accomplish that purpose.

5.12 How Low Fuel Prices are Impacting the Industry

From 2009-2012, when the federal government and CARB were developing new regulatory requirements for model years 2017-2025, the automotive marketplace appeared to be increasingly receptive to more fuel-efficient vehicles and PEVs. From 2000-2012 the average fuel price (nominal) climbed from roughly $1.00 per gallon to almost $4.00 per gallon. The small-car market share was on the rise (from 15.2% in 2000 to 19.6% in 2012). The market shares of large SUVs and pickup trucks were declining. Additionally, both HEVs and diesels were capturing larger market shares. Not surprisingly, NHTSA (2012a) assumed that the gradual shift in market share from light trucks to cars would continue from 2017-2025.

In the four years since the regulations were finalized, the patterns of consumer purchasing decisions in the automotive marketplace have begun to change significantly. Responding to the global glut of oil supplies, national average fuel prices dropped to as low as $1.92 per gallon in December 2015. Fuel prices recovered modestly to $2.20/gallon in December 2016, as OPEC and Russia agreed—at least temporarily—to concerted production cutbacks (Clarissa Jones 2017). Some experts are projecting fuel prices to rise to a national average of $2.49 per gallon in 2017 but few experts are forecasting a return to $4.00 per gallon for the foreseeable future (Colias, Roberts, and Rogers 2016).

Low fuel prices have had predictable impacts on the market: the small-car market share has declined; the pick-up truck share is no longer on the decline; the SUV market share is rising, driven by crossover sales; and the market shares of HEVs and diesels are declining. Furthermore, after five years of significant growth (2010-2014), the absolute number (as well as share) of PEVs sold in the U.S. declined in 2015, despite numerous federal and state incentives (EDTA 2016). PEV sales rose again in 2016 but the volume of sales per model (on average 5,000 units) is extremely small compared to what is typical for a sustainable, profitable product in the auto industry.

A consumer investment of $1,000 to $10,000 in fuel saving technology may seem attractive when fuel prices are $4.00 per gallon and rising, but the payback period on this investment deteriorates at low fuel prices. In Appendix I we supply a graphical demonstration of how consumer payback periods for fuel economy investments are sensitive to the fuel-price environment.

Only a few years ago, market analysts were projecting a 60-40 split, cars over trucks. Now analysts are projecting 60% truck sales for the foreseeable future. In December of 2016, light truck sales in the U.S. were over 63%. Table 5.1 illustrates this trend in market shares from 2009-2015 (Market Data Center 2016).

Table 5.1. Market Share of Passenger Cars vs. Light Trucks, Industry Classification

	2009	2010	2011	2012	2013	2014	2015	2016
Passenger Cars	52%	49%	48%	50%	49%	47%	43%	40%*
Light Trucks	48%	51%	52%	50%	51%	53%	57%	60%*

Source: Ward's Auto, 2016b; * preliminary

A recent study of consumers who traded in their HEV or PEV found significant differences in their 2015 decisions compared to 2014 and 2013. The percentage of the consumers who traded in for a new SUV was 22% in 2015 compared to 18.8% and 11.9% in 2014 and 2013, respectively. Loyalty rates for HEV and PEV owners fell below 50% in 2015 for the first time (Edmunds 2016a).

There is an emerging body of real-world evidence that consumers are not particularly inclined to purchase the fuel efficient and zero-emission vehicles that automakers are offering pursuant to regulation. Such evidence lends credence to the hypothesis that the stricter federal and ZEV requirements planned between now and 2025 could have an adverse impact on new vehicle sales.

5.13 How Might a Shift from Steel to Aluminum Impact Employment in the Supply Chain?

A consumer, at the time of purchase, may not notice whether their pickup truck is made predominantly of steel or aluminum. However, materials substitution can have an impact on employment in the supply chains for the two materials.

Diminished automaker demand for steel would affect steelmakers in the U.S. as well as companies that sell steel into the U.S. market from other countries. Each year about 25% of steel used in the U.S. is imported, and a major trade dispute exists between China and the U.S. and the EU on steel-related issues (USGS 2016a).

Both basic-oxygen furnace steelmaking (also called integrated steelmaking) and electric arc furnace steelmaking could be adversely affected (SASB 2014). The two supply chains are somewhat different, as are the plant locations in the U.S.

Integrated steelmaking, which accounts for about one-third of U.S. production, is concentrated in Indiana, Ohio, Michigan, and Pennsylvania (SASB 2014). Several steps are involved in integrated steelmaking, each associated with separate facilities (Elgowainy et al. 2016). Metallurgical coal is used in the production of coke. Coke, iron ore, and limestone are then used to make molten iron in a blast furnace. Molten iron, often supplemented with manganese, is then blown with oxygen in the basic oxygen furnace to produce steel. Separate finishing facilities prepare and shape the steel for use in specific applications such as oil pipe and flat-rolled product for vehicle body panels. The auto industry consumes about 17% of the steel produced at basic oxygen furnace facilities (SASB 2014).

Electric arc steelmaking, which accounts for two thirds of U.S. steel production, uses primarily scrap steel, limestone, and iron as inputs; much of the scrap comes from the auto industry. The inputs are melted and refined through oxidation. The numerous "minimills" that perform EAS are spread across the country, with large ones located in Pennsylvania, Colorado, and Mississippi.

Diminished demand for steel may lower employment of U.S. workers in the supply chain for steel but greater use of aluminum should boost employment in the supply chain for aluminum. The supply chain, though, is quite different for aluminum.

Producing aluminum begins with the mining of bauxite, which occurs primarily in tropical countries. The U.S. relies 100% on imports, predominantly from Jamaica, Guinea, and Brazil. Bauxite is then transformed into aluminum oxide at alumina refineries. There are some domestic refineries (Texas and Louisiana) but most of the work is done at refineries in Canada, China, and Venezuela (the latter country is the dominant exporter to the U.S.).

Aluminum oxide is the key input at primary aluminum smelters, where an electricity-intensive electrolysis process is used to extract the aluminum. The U.S.-based smelters are operating in Indiana, Washington, New York, South Carolina, Kentucky, and Missouri, but the U.S. industry is declining rapidly due to import competition. In 2015 imports accounted for 40% of the aluminum consumed, with Canada serving as the largest exporter to the U.S. (USGS 2016b). Most of the world's new capacity in primary aluminum production is located in China, and the U.S. and the EU are also in trade disputes with China over aluminum supply and pricing (Glassman 2016). Use in automobiles accounts for about a quarter of U.S. aluminum consumption (Menzie et al. 2010).

Alternatively, aluminum is produced at recycling facilities, which entails scrap preparation, melting, and ingot casting. For high-quality automotive parts, the cast and wrought materials are typically separated to ensure that the chemistry of the recycled parts is desirable and consistent (Elgowainy et al. 2016). About 30% of the aluminum produced in the U.S. comes from recycled scrap.

As the midterm reviews consider the impact of regulatory requirements on the employment of workers in the U.S., as required by presidential executive order, it is crucial to consider all of the impacted supply chains, not just workers at assembly plants and dealers. Changes in materials use can have complex impacts, positive and negative, in different sectors of the economy and regions of the country.

5.14 How Might a Shift from the ICE to PEVs Impact Employment in the Supply Chain?

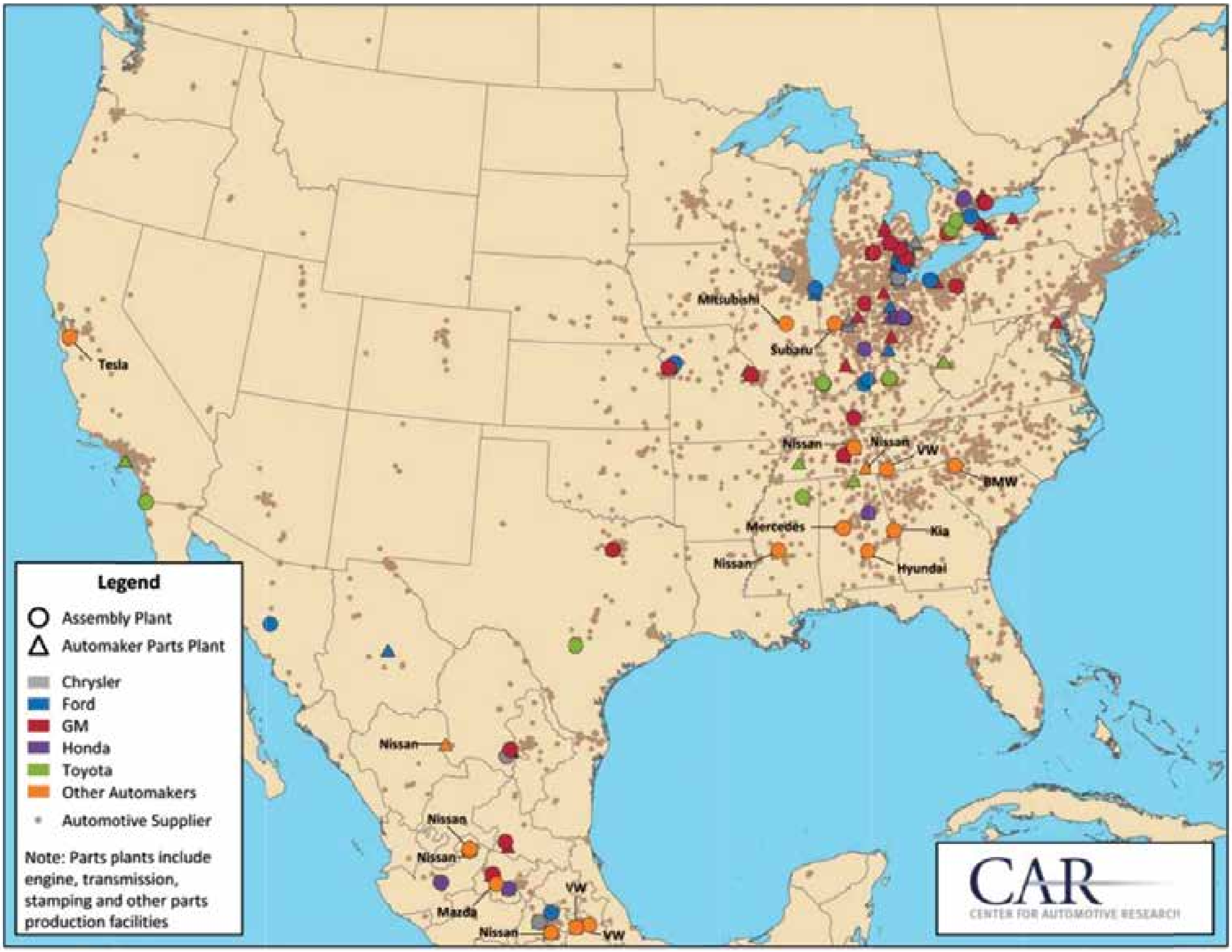
Passenger vehicles must be assembled regardless of whether the vehicle's energy comes from a gasoline engine or electricity. Although a shift from internal combustion engines to PEVs may not necessarily affect vehicle assembly plants, the shift could have a major effect on the level and geographic distribution of employment in the automotive supply chain (See Figure 5.1).

When shifting to PEVs, we should theoretically expect changes in employment due to the difference in the import ratios for the two propulsion systems and their supply chains, and the difference in the labor intensity of production of the two propulsion systems. The location of U.S. production facilities will reflect natural resource geography, access to markets, and other factors.

Table 5.2 lists the major U.S. plants that manufacture engines for use in passenger cars and light trucks. Their locations are concentrated in the Midwest and South, with none on the East or West coasts. It is more difficult to trace all of the component manufacturers that supply the engine/transmission plants, since they may have multiple customers in different sectors of the economy. Producers of the following components may also be at risk of diminished demand for their product: gasoline tank, gasoline pump, electronic fuel injection, alternator (for power to accessories), and pollution control equipment (e.g., catalysts and particulate traps).

A shift from gasoline engines to PEVs might lower production volumes and employment in some of the plants that produce engines and components, but there are several important qualifications. First, in the near-term, plants that produce engines for light trucks are less likely to be adversely affected than plants that produce engines for cars, since it is more economically efficient for automakers to electrify a car than a truck. Second, for competitiveness reasons, car manufacturing (including engines) in North America has been trending to Mexico for several years (CAR 2016), and, therefore, U.S. employment may decline in the car sector with or without

Figure 5.1. North American Automaker and Automotive Supplier Production Facility Locations



Source: CAR, 2015

Table 5.2. Engine Plants by State 2010-2015 (Number of Engine Plants/Number of Engine Components Plants)

	2010	2011	2012	2013	2014	2015
Alabama	3/0	3/0	3/0	3/0	3/0	3/0
Indiana	1/1	2/1	2/1	2/1	2/1	3/1
Kentucky	2/0	2/0	2/0	2/0	2/0	2/0
Michigan	8/4	7/4	7/4	7/4	7/4	7/4
New York	1/0	1/0	1/0	1/0	1/0	1/0
Ohio	4/1	4/1	4/1	4/1	4/1	4/0
Tennessee	2/0	2/0	2/0	2/0	2/0	2/0
West Virginia	1/0	1/0	1/0	1/0	1/0	1/0
Wisconsin	1/0	0/0	0/0	0/0	0/0	0/0

Source: Wally Wade, personal communication, December 5, 2016 based on Ward's data a shift to PEVs. Third, a shift to PHEVs (rather than BEVs) might have little adverse effect, since PHEVs still require gasoline engines.

For comparison, we consider the manufacturing of BEV components, as BEVs have a relatively simple propulsion system: an automotive-grade lithium ion battery pack (which stores energy); a charger (which replaces expended energy); an electric motor (which provides the force for mobility); and converters (to power accessories). The most significant components in the value chain are the battery cells and packs, since they account for a majority of the cost of the electric propulsion system (NRC 2015a; NRC 2015b; Canis 2013).

Battery manufacturers in Japan, China, and South Korea have strong competitive advantages over new entrants for several reasons. Following the early success of Sony, Asian companies have dominated consumer electronics for more than a decade. Asian firms receive support from their governments, financially and otherwise (Canis 2013); (Chung, Elgqvist, and Santhanagopalan 2015). For these companies and their suppliers, batteries for use in PEVs are another exciting application.

The incumbent Asian producers of battery cells enjoy many technical and cost advantages: processing expertise from high cumulative rates of production for different applications; an ability to spread overhead and fixed costs across multiple products; strong purchasing power with suppliers; an established regional supply chain with clusters and collaborative relationships; and an ability to reassure vehicle manufacturers that they are financially strong and can produce with high quality. In this sector, there are high costs of entry, low margins due to intense competition, and limited opportunities for differentiation in vehicle performance.

The competitive advantages of the Asian companies are by no means permanent. Japanese firms were dominant in the 1990s for consumer applications, but the emergence of strong Chinese and Korean competition has caused less dependence on Japanese firms (Chung, Elgqvist, and Santhanagopalan 2015).

While there are intensive R&D programs underway in the U.S. aimed at developing alternatives, the lithium ion battery system is seen as crucial for near-term—next decade—applications in PEVs (NRC 2015a; Sandalow 2009). In 2009 the new Obama administration recognized the poor competitive position of the U.S. Several U.S.-based companies tried to enter this sector with generous subsidies and loan guarantees from the U.S. Department of Energy but the U.S. companies have had uneven success rates (Canis 2013). Battery maker A123 of Massachusetts, for example, ultimately filed for Chapter 11 and emerged from bankruptcy with a new owner and business plan that did not focus primarily on batteries for PEVs in passenger vehicles. In recent years, Asian battery makers have actually consolidated their dominant position globally. Meanwhile, the three largest-selling PEVs (by U.S. sales volume)—the Tesla Model S, the Nissan Leaf, and the Chevrolet Volt—are each making use of Asian battery technology.

The U.S. employment ramifications of a shift to PEVs require a careful look at each stage of the production of lithium ion battery cells and packs, and at potential opportunities for production by facilities located in the U.S., regardless of owner or headquarters location (Becker, Sidhu, and Tenderich 2009). The situation is complicated by a global overbuild of the battery industry that depressed prices and discouraged investments for several years (Chung, Elgqvist, and Santhanagopalan 2015).

The key raw materials for batteries are plentiful in multiple regions of the world but the U.S. is positioned poorly at the present time. Lithium is mined primarily in Chile and Argentina. The Democratic Republic of Congo is the primary producer of cobalt. Some of the rare earth minerals are mined predominantly in China. The U.S.-based company Molycorp (MCP) owned the Mountain Pass rare earth mine in California and made a multi-year effort to enter the rare earth mining business. They filed for bankruptcy in June 2015 (Yan 2015). Efforts are also underway in Australia to compete with the Chinese on rare earths (Lo 2015).

Once the raw materials are mined, they must be transported to specialized facilities for (1) processing, for purity and specific composition, (2) production of battery cells, and (3) production and assembly of battery packs, including electronic control units and cooling systems. The integration of the battery pack into the vehicle is typically done at the vehicle assembly plant (Boston Consulting Group 2010).

There are numerous U.S. firms positioned to play a role in production of components for PEV-purposed lithium ion batteries such as lithium hydroxide, lithium carbonate, cathode and anode powders, cathode precursor materials, graphite anodes, separators, polypropylene and polyethylene films, battery management systems, and electric drivetrains. The potentially competitive U.S. companies are often large firms (e.g., 3M, DuPont, Celgard, ConocoPhillips, Superior Graphite, and Dow) that typically make individual components for PEVs that are also useful in other industrial applications, although usually with a specialized adaptation.

Production of battery packs will likely be concentrated in locations where PEVs are assembled because packs are not cost-effective to ship and are specific to the PEV models in which they will be employed (Chung, Elgqvist, and Santhanagopalan 2015). LG Chem of South Korea has a battery plant in Michigan to serve GM. As another example, NEC Corporation of Japan is a partner at Nissan's battery plant in Smyrna, Tennessee.

Tesla's plans for entering the lithium battery business are ambitious in size and scope (Clark-Sutton et al. 2016; Niedermeyer 2016). They've partnered with Panasonic of Japan in the massive Gigafactory that is now under construction near Sparks, Nevada. The Gigafactory will produce battery cells as well as battery packs, and is expected, when it opens in 2018, to be the largest battery manufacturing facility in the world. It appears that the Tesla packs will then be used to assemble PEVs at a vehicle assembly complex near Fremont, California, where GM and Toyota once produced vehicles in a partnership (Chappell 2016).

From a U.S. employment perspective, the Tesla approach is more promising than the Nissan and GM approaches but it remains to be seen whether Tesla will succeed commercially and whether other companies will replicate the Tesla approach. Tesla's sales volumes are increasing for its two upscale Models (the X and S) and they have 400,000 customers that have placed orders ($1,000 down) for the forthcoming mainstream Model 3 (Fehrenbacher 2016a). But Tesla has been running into unexpected product-quality problems as it rapidly increases production volumes, a problem that is common as start-ups strive to become profitable, high-volume producers (Fehrenbacher 2016b; T. Higgins 2017; Burke 2016).

The history of the Toyota Prius is a cautionary tale in this regard. Toyota has long considered making the popular Prius—and presumably its batteries—in the U.S., but instead continues to import the vehicle into the U.S. from Japan. In 2010, Toyota decided publicly against producing the Prius at its Mississippi plant and instead decided to build the Corolla there (Kim 2010). The Toyota decision has not changed since then, even though the Prius has achieved high U.S. sales volumes and was the number one selling passenger vehicle in California in 2012 and 2013. In fact, the Prius ranks among the lowest in domestic content among passenger vehicle models sold in the U.S. (DuBois 2016; Wade 2016).

Suppose the gasoline engine is compared to electric propulsion from the perspective of overall labor input throughout the supply chain. Which system requires more labor? Since a PEV is currently about $10,000 more expensive to produce than a comparable gasoline engine, it would seem that at least some of that extra cost is paying for labor. However, the cost of specialized materials comprise 70-80% of the cost of producing the battery cells, with labor less than 10%, and the cost of the cell production is the single largest contributor to the cost of the battery pack (Canis 2013; Chung, Elgqvist, and Santhanagopalan 2015).

There are no rigorous studies with hard data on the extent of labor inputs in the two supply chains. One European study, based on interviews of European auto producers and suppliers, speculated that the labor intensity of PEV production is probably lower than it is for gasoline engines. That study concluded that the long-run economic advantages of BEVs rest in ownership savings for the consumer, not higher employment levels throughout the supply chain (de Bruyn et al. 2012).

6. REVIEW OF PREVIOUS INDUSTRIAL IMPACT STUDIES

Regulation of the automotive industry is not a new phenomenon. CARB and EPA have extensive regulations covering the tailpipe emissions of "criteria" air pollutants, such as those that are related to smog and soot. NHTSA has extensive regulations on vehicle safety that cover issues as diverse as brake systems and fuel tank integrity. Even regulations of fuel economy are not new, as the largest increase in federal fuel economy standards occurred in the decade after the 1973-4 Arab oil embargo. Although there is extensive literature on the costs and benefits of these programs tracing back to the 1970s (e.g., see L. J. White 1981), little is known as to whether these regulations impacted the rate of new vehicle sales.

Casual empiricism can easily lead to contradictory conclusions. For example, after the decade of frozen standards (1996-2004), CAFE requirements were raised for light trucks beginning in model years 2004-7, and the automotive industry entered a deep recession starting 2008. Yet, it is well known that the unexpected bubble in housing prices and the financial crisis caused the Great Recession of 2007-9, and the severe contraction of liquidity crippled auto sales. The correlation with the onset of light truck CAFE standards is coincidental.

Likewise, the CAFE standards for cars and light trucks were gradually tightened from model years 2008 through 2016, the same period that the auto industry experienced a remarkable recovery in new vehicle sales. The recovery is related to record low interest rates, declining unemployment, rising consumer confidence, and increasing wealth and income at the top quartile of the income distribution (the group that dominates new vehicle sales). Whether the CAFE standards had any role in restraining or accentuating the recovery in the auto sector has not been studied explicitly; it is quite possible that the correlation between stricter CAFE regulation and auto recovery is coincidental, a point that (EPA 2016a) acknowledges.

6.1 Review of Existing Studies

Looking forward, the combination of the two federal programs and the two CARB programs could have a significant impact on the automotive industry, yet we found remarkably few studies of the possible industrial impacts. Our search for studies included both government reports and the academic, advocacy, and think-tank literatures. The following screening criteria were employed: the authors addressed the 2017-2025 federal and/or California standards, and the impact of the standards on new vehicle sales and/or employment. The eight studies we found are reviewed briefly below.

NHTSA (2012a) and EPA (2012a) provide the official regulatory impact analyses in support of the federal CAFE and GHG standards, respectively, for model years 2017-2025. Both reports include a detailed engineering-economic analysis of compliance technologies, including their costs and fuel-consumption benefits, but differ in their commitment to the likely employment effects. On the one hand, the NHTSA analysis provides alternative scenarios in which the quantitative impact of the standards on new vehicle sales is either positive or negative, depending upon consumer reactions to higher vehicle prices and estimated savings in fuel expenditures. Employment impacts are positive or negative, depending on the scenario. On the other hand, EPA (2012a) includes a qualitative discussion of possible impacts on new vehicle sales but no quantitative modeling. A consumer payback analysis is performed that shows that consumers will reap sufficient fuel savings to pay for the higher vehicle prices in a short period of time. Some positive employment impacts are quantified in sub-sectors that produce green automotive technology.

The official regulatory impact analysis in support of the California ZEV standards for model years 2018-2025 examines only economic impacts in California and does not address the other nine ZEV states or the national economy (CARB 2011a). With a methodology similar to NHTSA (2012a), CARB (2011a) finds that the ZEV program will increase new vehicle sales because the fuel savings from ZEVs will ultimately be larger than the incremental cost of the ZEV technology. Specifically, a consumer payback analysis shows that fuel savings from at least one type of BEV will be sufficient to cover the higher price of the vehicle over the lifetime of the vehicle.

Positive employment impacts are quantified for the State of California (e.g., in firms that produce recharging stations for plug-in vehicles).

We also reviewed economic impact analyses produced by four think tanks. Although most of the studies focus on the 2012-2016 and 2017-2025 standards, there is some variation in the MPG targets underlying the estimates. For example, CAR (2011) studies the impacts of the 2017-2025 standard under assumption of 47, 51, 56, and 62 MPG in 2025; Wagner, Nusinovich, and Plaza-Jennings (2012) study the impact of meeting the standards for model year 2017-2025; and Busch et al. (2012) assume a fuel economy of 54.5 MPG by 2025.

Busch et al. (2012) from the Blue-Green Alliance do not model vehicle-sales impacts but they do produce estimates of employment impacts. They combine technology cost estimates from the federal regulatory impact analyses with social accounting matrices that are taken from the Minnesota IMPLAN Group to estimate the macroeconomic effects of the federal standards using the Dynamic Energy Efficiency Policy Evaluation Routine (DEEPER) model. The model used in the analysis has 14 economic sectors and one household sector. Busch et al. (2012) assume that fuel savings are distributed across the economy in proportion to 2010 consumption, that 80% of the additional spending on technology required to meet the standard will go to the parts and supplies sector (and 20% to vehicles), and that the government's administrative costs will be $30 million per year in real 2010 dollars. They find that CAFE will create approximately 320,000 jobs by 2025 and 570,000 by 2030. A breakdown by sector reveals employment gains for every sector except oil refining and oil and gas extraction; the largest gain is in the business and personal services sector. They further find that net real (2010 $) wages and GDP increase by $49 billion and $75 billion, respectively, by 2030. Finally, they estimate the employment impacts of an increase in the domestic content of cars to 75% and find that direct auto-manufacturing jobs would increase by 3,300 by 2025 and 4,100 by 2030. Total number of jobs created by this increase in content is 10,000 by 2025 and 13,000 by 2030, in their estimate.

CAR (2011) prepared a study prior to the completion of the joint federal rulemaking, but the range of rulemaking options it examines includes the 54.5 MPG standard that was finalized by NHTSA/EPA. CAR begins its analysis with the technology-cost estimates from the NRC (2010), to which it makes several updates. CAR assumes a greater reduction in vehicle mass compared to the NRC (2010), and also includes cost estimates for PEVs, on the assumption that some PEV production will be necessary to comply with the federal standards. CAR then estimates the mix of technologies that is able to achieve four different levels of CAFE standards relative to a baseline of model year 2008: 47, 51, 56, and 62 MPG. The average per-vehicle cost of achieving each of the CAFE standards is determined based on the combined weighted cost of implementing that technology mix. CAR then estimates the fuel cost savings of each technology mix at two alternative gasoline prices ($3.50 and $6.00), and the authors net the fuel savings from the increased cost per vehicle. CAR determines economic impacts by first estimating the price elasticity of motor vehicle expenditure (% change in expenditure due to a 1% increase in price) and uses this estimate to determine the impact of the increased net price on vehicle demand. The change in vehicle sales is translated into U.S. vehicle production and employment using data on the domestic sourcing ratio and automotive labor-market productivity. All rulemaking scenarios analyzed by CAR produce a decline in vehicle sales and employment except one: a standard of 36 miles per gallon where the price of fuel is pegged at $6 per gallon.

In 2016, CAR released another report positing potential effects of the federal regulations covering the 2017-2025 period on the U.S. economy. CAR starts by considering expected changes in vehicle fuel economy over the regulatory period based on mandate standards, as adjusted for real-world driving conditions. Projecting that real-world fuel economy of the average vehicle will increase by 12.7 MPG between model years 2016-2025, CAR assumes three compliance cost estimates—$2,000, $4,000, $6,000—assuming that for every one mile-per-gallon increase in vehicle fuel economy the average per-vehicle cost would increase by a range of $200-400. CAR employs the EIA's most recent low ($2.44 per gallon), most likely ($3.00 per gallon), and high ($4.64 per gallon) gasoline forecasts for 2025 to estimate fuel savings over a 3.4 year period, accounting for average miles traveled and expected rebound effect. Based on the three mandate cost levels and three different gasoline price forecast values, CAR estimates nine scenarios to calculate the net cost of buying a 2025 vehicle. Based on the results, and assuming a long-run own-price elasticity of .61, CAR estimates effects on motor vehicle demand. The change in vehicle sales is translated into U.S. vehicle production and employment using data on the domestic sourcing ratio and automotive labor-market productivity. Overall, CAR finds the effect of the federal regulations on sales revenue in 2025 ranges from +.82 percent at a fuel price of $4.64/gallon and a fuel economy mandate cost of $2,000 to -8.6 percent at a fuel price of $2.44/gallon and a mandate cost of $6,000. The changes in auto industry employment range from an increase of 15,700 at a fuel price of $4.64/gallon and a mandate cost of $2,000 to a loss of 137,900 at a fuel price of $2.44/gallon and a mandate cost of $6,000.

Wagner, Nusinovich, and Plaza-Jennings (2012) from the National Automobile Dealers Association (NADA) calculate the share of consumers who meet the minimum debt-to-income (DTI) ratio required to finance the purchase of the cheapest new vehicle available on the market before and after the stricter CAFE standards. Drawing on technological costs from the federal RIAs, they assume that the cheapest new vehicle will increase in price by between $2,937 and $12,349 (in 2010 $) after complying with the new CAFE standards. They further assume that a consumer will only receive a loan if their DTI is less than 40%. The main finding is that compliance with the new CAFE standards will lead to a significant drop in new vehicle sales because a large number of consumers fail to meet minimum DTI requirements. The cheapest new vehicle will cost approximately $15,700 under CAFE, and this price would reduce the number of people with qualifying DTI by approximately 5.8 to 6.8 million. The study's worst case scenario of a $12,349 price increase would cause approximately 27.7 million consumers to drop out of the market.

Baum and Luria (2010) do not model vehicle sales impacts but do supply employment estimates. They rely on the technological cost estimates produced by The Panning Edge to estimate macroeconomic impacts using the Regional Economic Model Inc. They report that every packet of 100,000 traditional U.S.-made vehicles is associated with 17,000 jobs; this estimate is made after making adjustments for increased labor productivity and reduced U.S. content. They then assume that employment is proportional to the cost of manufacturing the vehicle, which they further assume is approximately 80% of the listed price. From this calculation they conclude that an energy-saving technology that adds $500 to the cost of each vehicle is associated with 2.5% of the 17,000 jobs mentioned above. More recently, Baum and Luria (2016) examined the economic impact on the Big Three of the 2022-2025 federal standards compared to scenarios where the standards are weakened. Under most scenarios examined, they conclude that the Big Three and their suppliers will profit from the 2022-2025 standards because, unless fuel prices are below $2.60 per gallon, the Big Three can pass the full technology cost ($1,353 per vehicle) on to consumers. They do not model the impact of the higher prices on new vehicle sales.

6.2 Limitations of Existing Studies

This body of literature contains several major limitations that pertain to information and assumptions. First, none of the studies incorporate the California ZEV program in conjunction with the federal standards. The impact on industry is understated due to the omission of the ZEV program. Second, the studies make conceptually different assumptions about employment impacts: some assume that regulatory costs reduce employment because the resulting price increases reduce vehicle sales and vehicle-related employment; others assume that regulatory costs increase employment because regulatory costs are related to increased employment in the green technology sector. Different assumptions need to be reconciled. Third, few of the studies had access to NRC's (2015a) update of the costs and fuel-consumption benefits of alternative technologies. Fourth, the studies were typically performed before the collapse of global oil prices and the downward forecasts for fuel prices between now and 2025. Finally, the studies are inconsistent as to their baseline assumptions (i.e., how the industry—sales and employment—would have fared without the stricter federal and state requirements) and, in some cases, the baseline assumptions are not transparent. For example, in the absence of the tighter standards from 2017 to 2025, the baseline descriptions of vehicles do not account for future growth in fuel-expending features such as increased performance, safety, and new emission control standards for criteria pollutants. In Appendix III, we offer some suggestions for how the baseline issue should be handled in future RIAs such as reforms to the model year 2022-2025 federal standards.

In addition to these limitations, previous RIAs prepared by the EPA, NHTSA, and CARB are marked by three important methodological limitations as well. First, the approaches taken to model the macroeconomic impacts of the regulations are overly simplistic and do not capture dynamics within the economy (e.g., the interactions of different subsectors of the U.S. economy such as gasoline consumption and motor vehicle production). Second, modeling exercises in these RIAs do not always treat consumer demand for vehicles as endogenous, but instead assume that consumers will continue to purchase vehicles at the same rate as they would in the absence of the regulations. Third, the RIAs present national-level estimates of new-vehicle sales and employment impacts but do not additionally disaggregate these results to the regional or state levels. The related analytic work published in TAR (2016) and the recent (EPA 2016a) determination suffer from similar limitations.

An enhanced methodological approach should account for two major real-world processes. The first is the technological component, in which auto manufacturers respond to federal and state mandates by altering their vehicle technologies. The RIAs and TARs (TAR 2016; EPA and NHTSA 2012) are generally strong in their treatment of these engineering issues, though important controversies remain. The second process is the macroeconomic component, in which the analyst simulates the effects of changes in vehicle prices, vehicle sales, and gasoline consumption on the performance of the U.S. economy. For example, one can model how the impacts of the regulations work through the economy and impact key macroeconomic variables such as U.S. gross domestic product, employment levels, income levels, or impacts on specific economic sectors or regions of the country. These two processes (technological and macroeconomic) are generally modeled as separate steps due to the methodological capabilities and limitations of available modeling platforms.

The two processes lend themselves well to bottom-up and top-down models, respectively. A bottom-up model is a techno-economic model—also referred to as a “process-oriented model”—that simulates market dynamics due to technological or policy scenarios. These models are often based on cost minimization for achieving a regulatory objective and they tend to provide significant detail across different vehicle technologies and alternative sources of energy. Often, a bottom-up model will treat the regulated firm as the unit of analysis. A top-down model, on the other hand, tracks market supply and demand over time and within aggregate economic sectors, regions, or the U.S. economy as a whole. Different top-down modeling techniques include input-output models, computable general equilibrium (CGE) models, and econometric models.

Previous studies of CAFE have used a combination of these types of models, or more simplified modeling approaches. Regulatory impact analyses of the GHG and CAFE standards, such as those prepared by the EPA and NHTSA, focus the majority of their efforts on bottom-up modeling to compute average vehicle production costs, and then use simplified calculations to derive potential employment impacts due to the changes in the costs of producing new vehicles. The EPA, for example, uses the Optimization Model for reducing Emissions of Greenhouse Gases for Automobiles (OMEGA)—a bottom-up model of the transportation sector—to simulate those vehicle packages that different manufacturers will use to comply with regulatory requirements. From this model, they extract estimates of the average upfront cost of producing vehicles that will be sold to comply with the standard. EPA is now taking the position in the draft TAR (2016) that it is not technically feasible to estimate changes in new vehicles sales, since not enough is known about how consumers will react to more costly vehicles that have higher fuel economy. The agency is working on a vehicle choice model that, when linked with the results of the OMEGA model, will generate estimates of changes in new-vehicle sales, but it is unclear when the agency will start using such a model in RIAs of vehicle regulations.

Furthermore, in the absence of estimates of changes in new-vehicle sales, the EPA relies solely on the cost information to determine the favorable employment impacts of the regulation. That is, the agency estimates the overall cost of compliance, and then applies a ratio of workers per $1 million spent in the automobile sector, weighted by the percentage of vehicles that are produced in the U.S. relative to those imported (also framed as the ratio of domestic production of vehicles to domestic sales of vehicles). EPA does not consider the fact that when consumers spend more money on vehicles, they have less money available to spend on other goods and services such as housing, food, and recreation. Nor does EPA analyze that the savings in gasoline will have two opposing effects on the economy: reduction of U.S. production, refining, and transportation of petroleum and petroleum products, and an increase in consumer spending on other goods and services such as housing, food, and recreation.

In a similar bottom-up process, NHTSA uses the Volpe model—also referred to as the CAFE Compliance and Effects Modeling System—to estimate vehicle costs. Like the OMEGA model, the Volpe model assembles vehicle-technology options from which manufacturers may choose in a constrained cost-minimization model.

For impacts on vehicle sales, NHTSA goes beyond the EPA approach and performs several scenario analyses using a total cost-of-ownership (TCO) model. Most of the scenarios show positive impacts on vehicle sales but some show negative impacts. They then take the derived vehicle-sales estimates and divide by the average number of vehicles that an employee produces in a year, as they assume this calculation can serve as a measure of "job years." They then multiply this estimate by the same ratio of domestic production to domestic sales as used in the EPA analysis. Both the NHTSA and EPA employment estimates only apply to the auto industry, and do not extend to other sectors of the economy through ripple effects or multipliers.

The CARB RIA examines macroeconomic impacts only from the perspective of the State of California using a modified version of a computable equilibrium model used by the California Department of Finance called the Dynamic Revenue Analysis Model (DRAM). The modified model is called the Environmental-DRAM and is designed to support analyses of economic impacts of large-scale environmental regulations. With regard to new vehicle prices, they estimate that the ZEV requirements reduce the operating costs of vehicles by a magnitude larger than the technology costs of ZEVs. As a result, net vehicle prices decline and new vehicle sales rise. CARB finds that the ZEV requirements have positive overall impacts on the state of the California economy. As explained earlier, the CARB analyses do not consider interaction issues with the federal programs or the economic impacts generated by the nine states that have chosen to enact and implement the California ZEV program.

This basic overview of the methodological approaches used in the RIAs highlights the observation that the regulatory agencies used simplified assumptions to derive employment impact estimates. It is important to note, however, that the main objective of the RIAs was to provide societal benefit-cost analyses of rulemaking, and not to produce estimates of macroeconomic impacts. Yet, as argued earlier in this report, an assessment of the effects of CAFE and other transportation regulations on the U.S. economy is fundamental to our understanding of how these regulations will perform.

Through the use of simplified assumptions about the manner in which vehicles sales will affect employment, and without considering these effects through a dynamic modeling structure, these previous studies may have produced unrealistic estimates. Top-down models that can account for interactions among different economic sectors and long-term supply and demand balances, to list just two possible additions, could be used to produce a more detailed understanding of the impacts of these regulations on the U.S. economy.

The second methodological limitation of previous RIAs pertains to the way in which consumer decisions are modeled and, in particular, an inability to treat consumer demand as endogeneous within the models. An extraordinary feature of the OMEGA and Volpe models is the degree of technological detail about the vehicle options from which the model may select. The OMEGA model, for example, includes a few hundred vehicle options, with variations in vehicle class, vehicle type, engine size, valve train configuration, and valves per cylinder. This detail, however, comes at a cost, as it focuses exclusively on technological alternatives among vehicles and manufacturer decisions without considering consumer responsiveness to these technological decisions. These models also do not account for broader energy sector dynamics, such as the price of gasoline. Yet, one should expect that both the price of a vehicle and the price of gasoline will affect a consumer's interest in purchasing a vehicle.

The third limitation of previous modeling efforts—not limited to the RIAs but also including the majority of other grey literature, save a study by Bezdek and Wendling (2005)—is the lack of consideration of regional or state impacts. Sub-national analysis is important for understanding the effects of regulations, since automobile production and consumption are not spread uniformly across the U.S. Manufacturing centers and supply chain companies are geographically oriented, as are oil and gas extraction activities and refining facilities.

These three fundamental limitations of previous studies led us to a series of modeling approaches that can provide macroeconomic estimates, both national and regional, of the federal and state standards, plus a more sophisticated treatment of consumer responsiveness when estimating vehicle sales. The macroeconomic impacts of the federal standards are modeled using REMI PI+ 2.0.2, a combined input-output, computable general equilibrium, econometric, and economic geography model, and a total-cost-of-ownership (TCO) model. The former is used to produce estimates of employment, GDP, and personal disposable income; the latter, which offers more flexibility in its treatment of consumer demand, is used to produce refined estimates of percentage changes in new-vehicle sales. These modeling approaches are presented in the next section.

7. DEFINING THE 2012 AND THE 2016 PERSPECTIVES

A key input of the macroeconomic modeling is the gross price premium of the average vehicle attributable to the combination of regulations. We define the gross price premium as the average additional cost of producing a vehicle, assuming that the cost is passed on to the consumer in the form of higher vehicle price.

Our modelling efforts use datasets that reflect five distinct gross price premiums between the years 2016 and 2025, two of which correspond to information that was available in the year 2012, when the federal agencies finalized the national standards, and three of which incorporate new information that became available by 2016. In all modeling exercises presented in this report, we start with (1) "2012 Perspective EPA" and (2) "2012 Perspective NHTSA." We then extend our analyses with (3) "2016 Perspective High," (4) "2016 Perspective Low," and (5) "2016 Perspective COMET." This section describes the data sources for the two "2012 perspectives" and explains how we generate values to represent the three "2016 perspectives."

7.1 The 2016 vs. 2012 Perspectives

The 2012 perspectives are based on information that was available to the agencies during the 2009-2012 period, when the 2017-2025 federal standards were developed, proposed, and finalized. To construct the 2012 perspectives, we obtained or derived gross price premiums and other relevant data such as gasoline savings and number of vehicles sold from the EPA and NHTSA RIAs (NHTSA 2012a; EPA 2012a).

Compared to the 2012 perspective, the 2016 perspective: (1) offers new estimates of technology costs and fuel-saving effectiveness supplied by the National Research Council of the National Academies (NRC 2015a) that, based on an NRC simulation exercise, correspond to somewhat larger vehicle price premiums in the 2016 perspective compared to 2012 perspective, specifically for vehicles equipped with an internal combustion engine; (2) recognizes that the California ZEV requirements, which are undertaken pursuant to an EPA waiver, interact with the federal programs and will impact the automotive industry and the U.S. economy through some of the same mechanisms as the federal programs and in roughly the same time frame; (3) accounts for the new state of global energy markets, as characterized by significantly lower EIA forecasts of oil and gasoline prices through 2030; (4) accounts for new government forecasts of declining costs of producing plug-in electric vehicles based on innovation in lithium ion battery technology and production scale economies; (5) incorporates new information from the U.S. Department of Transportation on vehicle miles of travel by vehicle age, showing somewhat higher travel volumes in the early years of vehicle ownership and substantially lower travel volumes in later years of ownership; and (6), specifically, in the analysis of the total cost of ownership, accounts for new evidence from markets for new and used vehicles concerning how consumers react to changes in fuel prices and new technologies.

The first two items in the list above affect the price premium of a new vehicle and represent the principal difference between the various 2016 perspectives. The remainder of this section describes how we adjust the 2012 price premium to reflect the NRC (2015a) assessment of the federal programs and the California ZEV regulation.

7.2 The 2016 Perspective: NRC Adjustments

NRC, following a request by NHTSA, established the "Committee on Assessment of Technologies for Improving the Fuel Economy of Light-Duty Vehicles, Phase 2." The Committee was asked to conduct an assessment of the CAFE standards and provide recommendations that would be considered by NHTSA as part of the midterm reviews.

In 2015, the Committee published a report the central focus of which was the fuel-saving effectiveness and direct manufacturing costs of a series of technologies that automobile manufacturers could use to comply with the CAFE standards in the 2020-2030 period (NRC 2015a). After examining numerous technologies of different types, the committee confirmed the validity of most of the estimates of cost and fuel-saving effectiveness reported by NHTSA (2012a). However, for a limited number of technologies, NRC (2015a) found that both costs and fuel savings were underestimated or overestimated. NRC (2015a) also looked carefully at the estimated effects of multiple technologies, including the potential for interactions (synergisms or duplications).

Within the framework of their multi-technology assessment, the Committee provided a technology pathway example for a midsize car with an I4 DOHC spark-ignition (SI) engine and estimated the Direct Manufacturing Costs (DMC) for MYs 2017, 2020, and 2025 that would be required to comply with the CAFE standards. The two sets of estimates provided (namely a "low most likely" and a "high most likely"), as well as the original 2012 estimates from NHTSA, are illustrated in Table 7.1. All members of the Committee acknowledged uncertainty in the cost estimates, but some members believed that the low cost estimates were most likely to be correct while other members believed that the high cost estimates were most likely to be correct.

Table 7.1. Incremental Direct Manufacturing Costs (DMC) of a Mid-Size Car: Low Most Likely and High Most Likely Estimates

	Units	MY2017	MY2020	MY2025
NHTSA Mid-Size Car DMC Estimates	2010 $	1274	1184	1060
NRC Mid-Size Car Low Most Likely Estimates	2010 $	1381	1297	1181
Percent Difference (low)	%	8.40	9.54	11.4
NRC Mid-Size Car High Most Likely Estimates	2010 $	1923	1806	1658
Percent Difference (high)	%	50.9	52.5	56.4

Source: NRC, 2015, pages 276-277, 422-423.

Table 7.1 illustrates the percent difference in the DMC between the low/high most likely estimate and the DMC estimates based on the methodology that NHTSA adopted in the final rule. For MY 2025, the differences range from 11.4% (low most likely estimate) to 56.4% (high most likely estimate). We call these differences the NRC (2015a) high-cost estimate and low-cost estimate (adjustments), recognizing that both of them are considered most likely by some members of the committee. Table 7.2 shows how we have applied the NRC adjustments to NHTSA's (2012a) analysis.

The Committee notes that the cost estimates in Table 7.1 should not be considered forecasts of price premiums for a variety of reasons. Some of the sources of potential error were acknowledged by NRC; others have become

Table 7.2. Price Premium Adjustments Using the NRC (2015) Low Most Likely and High Most Likely Estimates

			Model Year								
Row ID	Source	Vehicle type	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	NHTSA	Car	$364	$484	$659	$858	$994	$1,091	$1,221	$1,482	$1,578
2	NRC low		$395	$526	$719	$940	$1,093	$1,203	$1,351	$1,646	$1,758
3	NRC high		$549	$733	$1,002	$1,309	$1,524	$1,681	$1,891	$2,307	$2,468
4	NHTSA	Truck	$147	$196	$397	$629	$908	$948	$1,056	$1,148	$1,226
5	NRC low		$159	$213	$433	$689	$998	$1,046	$1,169	$1,275	$1,366
6	NRC high		$222	$297	$603	$959	$1,392	$1,461	$1,635	$1,787	$1,918
7	NHTSA	Fleet	$287	$382	$567	$779	$964	$1,042	$1,165	$1,370	$1,461
8	NRC low		$311	$416	$619	$853	$1,060	$1,149	$1,289	$1,521	$1,628
9	NRC high		$433	$579	$862	$1,188	$1,478	$1,606	$1,804	$2,132	$2,285

Note: NHTSA refers to the data from the NHTSA 2012 RIA. NRC low indicates that the NHTSA numbers have been adjusted to reflect the NRC's low most likely estimate, and NRC high indicates that the NHTSA numbers have been adjusted to reflect the NRC's high most likely estimate. The price premiums in Table 7.2 account for both the Direct Manufacturing Cost (DMC) and the Indirect Cost (IC).

apparent since the NRC (2015a) report was published. We believe that use of the NRC cost adjustments in price-modeling exercises provides useful insight into some of the important uncertainties in estimating the impact of CAFE regulation on new vehicle sales.

Rows 8 and 9 in Table 7.2 capture the price premiums (i.e. DMC plus Indirect Cost) for the fleet that complies with the CAFE standards and is adjusted by the low (row 8) and high (row 9) most likely NRC estimates presented in Table 7.1. That is, the price premiums in rows 2, 3, 5, 6, 8 and 9 were calculated by applying the percentage differences from Table 7.1 to the NHTSA premiums in Table 7.2 (i.e. rows 1, 4 and 7). The percent differences for the low and high most likely estimates for MY 2018-2019 and 2021-2024 in Table 7.1 were calculated using a linear interpolation.

7.21 Cost versus Price

One of the main costs of the CAFE, GHG, and ZEV programs is the incremental increase in the cost of producing an average new vehicle. Since we make the standard competitive-market assumption that production costs are passed on to consumers in the form of higher prices, we refer to this incremental cost increase using the term "price premium." There are a series of analyses that support the view that most of the production cost increase will be passed on to the consumer in the form of higher prices (e.g., see Austin and Dinan 2005; CBO 2004; Anderson and Sallee 2011; Jacobsen 2013; CAR 2015). The federal agencies—NHTSA and the EPA—also adopt this assumption but they take different approaches in estimating the price premium by model year. We chose to adopt the approach taken by NHTSA since this is the approach that was examined and updated by the NRC committee described above.

NHTSA (2012a) identifies two types of price premiums: one based on the "estimated required" fuel efficiency, and one based on the "estimated achieved" fuel efficiency. The "estimated achieved" fuel efficiency considers a series of compliance tools or flexibilities that manufacturers have at their disposal in order to meet the CAFE standards. Those flexibilities, as described earlier in the report, encourage manufacturers to offer BEVs and PHEVs. Flexibility is also provided by allowing manufacturers to bank, carryback, and carry forward compliance credits, and to trade credits with other vehicle manufacturers. The analysis labeled "estimated required" does not allow for the compliance flexibilities mentioned above, but does consider the option to pay civil penalties. In the remainder of the report we focus on the "estimated required" analysis, since this is the one that NRC (2015a) critiqued, and it follows the mandate from Congress that NHTSA has, which is based on the EPCA.

Later in the report, we discuss the various factors that may cause an overestimation or underestimation of the vehicle price premiums. The presence of compliance flexibilities for manufacturers is one of those potential sources of error.

NHTSA used data on vehicles from 2008 and 2010 to develop a baseline in the final rulemaking—the 2010 data is considered to be a more up-to-date estimate. Table 7.3 includes the "estimated required" price premiums by model year based on the 2010 baseline. The data presented in Table 7.3 constitutes the "2012 Perspective NHTSA."

Table 7.3. Average Price Premium in Constant 2010 Dollars (2012 Perspective NHTSA)

	Model Year								
Vehicle Type	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Car	$364	$484	$659	$858	$994	$1,091	$1,221	$1,482	$1,578
Truck	$147	$196	$397	$629	$908	$948	$1,056	$1,148	$1,226
Fleet Avg.	$287	$382	$567	$779	$964	$1,042	$1,165	$1,370	$1,461

Note: The figures pertain to the "estimated required" analysis for the 2010 baseline fleet. The fleet average is the weighted average of the car and truck figures using NHTSA's sales mix forecasts.

Source: Federal Register, Table I-15, pages 62659-62660.

The “2012 Perspective EPA” is based on the information from EPA’s 2012 RIA. The EPA data on the average price premium is presented in Table 7.4.

Table 7.4. Average Price Premium in Constant 2010 Dollars (2012 Perspective EPA)

	Model Year								
Vehicle Type	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Car	$206	$374	$510	$634	$767	$1,079	$1,357	$1,622	$1,726
Truck	$57	$196	$304	$415	$763	$1,186	$1,562	$1,914	$2,059
Fleet Avg.	$154	$311	$438	$557	$766	$1,115	$1,425	$1,718	$1,836

Note: The figures pertain to the 2008 baseline fleet. The fleet average is the weighted average of the car and truck figures using NHTSA’s sales mix forecasts.

Source: Federal Register, Table I-24, page 62665.

7.22 Potential Sources of Overestimation of Price Premiums

Here we discuss a variety of factors that might cause the price premiums in Table 7.2 to be larger than what would actually occur in the real world, after the federal standards take effect.

1. Vehicle manufacturers can reduce costs by taking advantage of a variety of compliance flexibilities (e.g., banking of credits for use in later years, and trading credits with other manufacturers) that we described earlier in the report, although some of those flexibilities are temporary in nature (e.g., flexible fuel credits expire in 2018; alternative fuel vehicle credits expire in 2021). Additionally, companies must make sure that they have complied with the EPA program as well as the NHTSA program, and the flexibilities in those programs differ.

2. While NHTSA (2012a) and NRC (2015a) have forecasted that industrial innovation will cause some improvements in technology—lowered costs and/or higher fuel-saving effectiveness—by 2025, the rate of innovation may be larger than they have predicted, which would mean that the price premiums in Table 7.2 are too large. Indeed, NRC (2015a) pointed to promising new technologies in their report and some reviewers believe NRC should have forecasted even more innovation, based in part on the historical rate of decline in the costs of producing conventional hybrids (German 2015; German 2016a).

3. Federal agencies are providing compliance credits for some “off-cycle” technologies that were not fully evaluated by NHTSA (2012a) and NRC (2015a); insofar as those technologies are less costly or more effective than those considered by NHTSA and NRC, the price premiums in Table 7.2 will be inflated. For a review of off-cycle technologies and their significance in compliance for the industry, see EPA (2016c).

4. Instead of implementing new technologies, vehicle manufacturers may instead make other compromises in vehicle design that enhance fuel economy (e.g., less acceleration capability). Although performance decrements are contrary to the industry trend over the last 30 years, recent EPA (2016d) data suggest average horsepower is starting to decline. There is also some evidence that this happened in response to the early CAFE standards (Klier and Linn 2010) and, if that happens again in 2017-2025, the price premiums in Table 7.2 will prove to be too high, though consumers may be somewhat dissatisfied with the compromised design features (Duleep 2016).

5. Most vehicle manufacturers operate globally and therefore sell new vehicles in multiple countries around the world where consumers may differ in their sensitivity to price increases. Some of the costs of new technologies may be spread over products sold outside the U.S., thereby reducing the price premiums that will be observed on U.S. vehicles. However, U.S. consumers are among the wealthiest new vehicle purchasers in the world and may be relatively receptive to price increases.

6. Some of the technology costs may not be passed on to the consumer; instead, costs may be financed by lower wages, or benefits to workers, or by diminished returns to investors. Those financial ramifications would produce different macroeconomic impacts than are modeled in this report.

7.23 Potential Sources of Underestimation of Price Premiums

Here we discuss a variety of factors that might cause the price premiums in Table 7.2 to be lower than what will occur after the regulations take effect.

1. Some experts question whether the technology combinations selected in the algorithms used by NHTSA and NRC analysts—and in our COMET modeling—will be sufficiently effective in saving fuel to meet the model year 2025 standards (Novation Analytics, LLC 2015; Smith 2016). If not, vehicle manufacturers may need to resort to more widespread application of conventional hybrids and/or advanced diesel engines, which can easily add $3,000 to $8,000 in production cost per vehicle, especially for light trucks (NRC 2015a). In their most recent draft TAR (2016), NHTSA and EPA models produce conflicting estimates as to the extent of hybridization that will be required (NHTSA predicts more hybrids will be necessary than EPA does). These issues are being addressed in the public comment process related to the draft TAR.

2. The NHTSA 2012 cost estimates are based on the assumption that some vehicle manufacturers (i.e., those facing high costs of compliance) will choose to pay the historically small per-vehicle fines for noncompliance under CAFE rather than implement expensive technologies. This tactic is no longer available because the federal government has decided to adjust all noncompliance penalties for inflation, which may have the practical effect of enlarging the CAFE fines several fold (Beene 2016b). Moreover, the magnitude of the penalties under the EPA program are uncertain but are expected to be much larger than the penalties under the CAFE program. Thus, the cost estimates reported by NHTSA in 2012 are understated, since they assume that some manufacturers can pay small noncompliance fines to achieve compliance.

3. The NHTSA 2012 cost estimates are based on a carry-forward use of compliance credits that may not be comparably available under the EPA GHG program. Consequently, manufacturers may need to invest more in technology than NHTSA analysts estimated, since manufacturers must achieve compliance with both the EPA and NHTSA programs.

4. The NRC (2015a) cost adjustments were derived from a pathway analysis that was applied to a basic mid-sized car with a gasoline engine in the 2008-2010 period. As incomes grow, and if fuel prices remain low, by 2025 a basic mid-sized car with a gasoline engine is likely to have more fuel-consuming features (e.g., additional horsepower, interior volume, cargo-hauling capability, and safety features) than are apparent today. As a result, by 2025, more fuel-saving technologies will be needed for the basic vehicle. Thus, more expensive technologies will be required to comply with the federal standards (Duleep 2016).

5. The NRC (2015a) cost adjustments were derived for a mid-sized car. NRC did not calculate the cost premium for all cars and trucks. However, pathway analyses performed using NRC cost and effectiveness estimates for other vehicle classes were found to provide generally similar trends as the ones estimated for the mid-sized car (Wade 2016). In light of that finding, we assume that the cost premium increases that NRC estimated for the mid-sized car also apply to the average passenger vehicle, which includes small cars, large cars, premium cars, crossovers, SUVs, minivans and pickup trucks. That said, since new vehicle sales are moving rapidly away from mid-sized sedans to cross-overs, SUVs, and pickup trucks, and since the cost-effectiveness of technologies for larger vehicles may be weaker, the price premiums in Table 7.2 could be too low. We are already aware of some concerns that the costs of fuel-saving technologies for light trucks have been underestimated in the TAR (2016) (Dziczek, Smith, et al. 2016).

6. Federal agencies are changing the fuel used in compliance tests from 100% gasoline to a real-world mix of ethanol and gasoline. Because ethanol has less energy content than gasoline, the CAFE and GHG compliance tests could be more difficult to achieve with the blend than with pure gasoline, although federal agencies

are required to make a corresponding adjustment so that the standard is not more stringent due to ethanol blending. The more difficult it is to achieve compliance with a blended fuel, the more manufacturers will have to utilize expensive fuel-saving technologies.

7. If federal agencies underestimate the future market shares of light trucks relative to cars (e.g., due to low fuel prices), and because unit compliance costs are higher for trucks than cars, then the fleet-wide average price premiums will be too low.

7.24 Qualitative Uncertainty Assessment of Price Premiums

A key question is whether the actual price premiums for model years 2017-2025 could prove to be higher than those based on the NRC high-cost adjustment or lower than those based on the NRC low-cost adjustment. Taking into account all of the evidence that we have reviewed, we are not highly confident that the actual price premiums will be in the range of those reported in Table 7.2. However, our opinion is that it is more likely than not that the actual price premiums will be consistent with the figures in Table 7.2. Note that this opinion refers to the federal programs, without consideration of the cost implications of the ZEV program. We now turn to the ZEV issues.

7.3 The 2016 Perspective: California ZEV Program Adjustment

In order to estimate the effects of the ZEV program on vehicle price premiums, we employ a simulation approach, which is distinct from the formal COMET modeling described below. We begin by examining the projected penetration of BEVs and PHEVs in the ten states that have adopted the ZEV requirements. Table 7.5 presents the penetration rates projected by CARB (2011a) for TZEVs (mostly PHEVs) and BEVs in the State of California.

Table 7.5. Number of PHEVs and BEVs Expected Annually, 2018-2025

Year	BEVs	PHEVs	Total	% PHEVs	% BEVs
	(absolute number of vehicles)				
2018	13,900	61,300	75,200	82%	18%
2019	27,300	75,300	102,600	73%	27%
2020	37,700	89,100	126,800	70%	30%
2021	46,300	101,900	148,200	69%	31%
2022	52,600	116,300	168,900	69%	31%
2023	59,500	131,200	190,700	69%	31%
2024	64,200	146,900	211,100	70%	30%
2025	65,400	161,700	227,100	71%	29%
TOTAL	366,900	883,700	1,250,600	71%	29%

Note: We have excluded Fuel Cell Vehicles from the above table.

Source: CARB, 2012, Table 3.6, page 49.

We assume that the ZEV penetration rates projected by CARB in 2012, percentage wise, will be the same in the nine other states that have adopted the ZEV mandate, since CARB's "travel" provision and east/west pooling arrangements expire in the near future.

Our next step is to obtain estimates for the penetration of various categories of BEVs and PHEVs in the fleet, namely PHEV40, PHEV10, BEV200, and BEV100. Table 7.6 presents penetration rates estimated by the EIA (2016), with respect to each vehicle category. For example, in year 2017 the EIA (2016) estimates that PHEV40 will represent 54% of all PHEVs sold, while PHEV10 will make up the remaining 46%. Similarly, for 2018, BEV200 will make up 65% of all BEVs sold in that year, with BEV100 accounting for the remaining 35%. Note that the EIA projections presented in Table 7.6 do not account for BEV75 and refer only to cars (not light trucks).

Table 7.6. Shares of PHEV40, PHEV10, BEV200, and BEV100 as a Percentage of all BEV and PHEV Sales

Year	PHEV40	PHEV10	BEV 200	BEV100
	(shares expressed with respect to all PHEV sales)		(shares expressed with respect to all BEV sales)	
2017	54%	46%	54%	46%
2018	54%	46%	65%	35%
2019	59%	41%	69%	31%
2020	59%	41%	68%	32%
2021	58%	42%	67%	33%
2022	58%	42%	64%	36%
2023	56%	44%	61%	39%
2024	55%	45%	60%	40%
2025	52%	48%	60%	40%

Source: AEO, 2016

Next, we calculate the price premiums for BEVs and PHEVs. We use data from the draft TAR (2016) and capture the following cost components that are unique for BEVs and PHEVs: (1) batteries, (2) non-battery items, (3) in-home charger, and (4) labor costs for in-home charger installation. Our calculations are conducted for the small and standard car size classes, as they are the ones that will see the highest penetration of PEVs.

Given the uncertainty about battery costs, we conducted a supplementary analysis for the price premiums of BEVs and PHEVs using projections from the (DOE 2013). Table V.1 (provided in Appendix V) presents the price premiums for the different PEV categories by vehicle class (i.e., small and standard car) as well as by data source (i.e., TAR 2016 assumptions about battery costs vs. DOE assumptions about battery costs). A more detailed description of how those values were calculated is provided in Appendix V.

The final step in calculating the ZEV price premium consists of weighting the incremental price changes presented in Table V.1 by the shares of each PEV technology captured in Tables 7.5 and 7.6. Additionally, we incorporate the fact that the 10 ZEV states account for 30% of all vehicle sales in the U.S. and consider the minimum ZEV floor requirement from CARB (2011a) presented in Table 7.7. Equation 1 in Appendix V illustrates how the formula was used to derive the ZEV premium.

Table 7.7. ZEV Sales as a Proportion of Total LDV Sales According to the ZEV Regulation

	Model Year							
	2018	2019	2020	2021	2022	2023	2024	2025
Minimum ZEV Floor	2.00%	4.00%	6.00%	8.00%	10.00%	12.00%	14.00%	16.00%

Source: CARB, 2012, Table 2.10, page 29.

The results for the ZEV premium calculated from that equation are provided in Table 7.8.

We use the ZEV premiums calculated in Table 7.8 in order to determine the 2016 Perspectives, namely 2016 Perspective High and 2016 Perspective Low (presented in Table 7.9). The 2016 Perspective High is the sum of the NRC High premium (presented in row 9 of Table 7.2) and the ZEV premium based on the TAR data (presented in Table 7.8). The 2016 Perspective Low is the sum of the NRC Low premium (presented in row 8 of Table 7.2) and the ZEV premium based on the DOE data (presented in Table 7.8). The premiums for the two perspectives start at relatively low levels in MY 2017 ($420 for 2016 Perspective Low and $544 for 2016 Perspective High) but by

Table 7.8. ZEV Price Premium Based on TAR and DOE Data

	Model Year								
	2017	2018	2019	2020	2021	2022	2023	2024	2025
ZEV Premium (TAR)	111	72	141	208	271	331	388	442	440
ZEV Premium (DOE)	109	70	135	195	248	294	348	401	407

Note: Values are expressed in constant 2010 dollars. We have assumed a 3% minimum ZEV share for 2017 and have set the ZEV shares for 2018 in Table 7.5 equal to those of 2017.

MY 2025 they become substantially higher ($2,035 for 2016 Perspective Low and $2,735 for 2016 Perspective High).

As a rough check on the 2025 result, we performed a back-of-the-envelope calculation and compared it to the result that was discussed by EPA (2013) when CARB's request for a ZEV waiver was approved. If the incremental

Table 7.9. Average Price Premium due to Federal and State Regulations for the 2016 Perspective, High and Low, by Model Year

	Model Year								
	2017	2018	2019	2020	2021	2022	2023	2024	2025
2016 Perspective Low	$420	$486	$754	$1,048	$1,308	$1,443	$1,637	$1,922	$2,035
2016 Perspective High	$544	$651	$1,003	$1,396	$1,749	$1,937	$2,192	$2,574	$2,725

Note: 2016 Perspective High is the sum (by Model Year) of the following premiums: NRC High (row 9 on Table 7.2) + ZEV premium (TAR) (Table 7.8). 2016 Perspective Low is the sum (by Model Year) of the following premiums: NRC Low (row 8 on Table 7.2) + ZEV premium (DOE) (Table 7.8).

cost of producing the average ZEV is $10,000, and if ZEVs penetrate 15.4% of the light-duty market in 10 states comprising 30% of the new vehicle fleet in 2025, then the average price premium in 2025 due to the ZEV requirement should be about $462 per vehicle ($10,000 x 0.154 x 0.3). By way of comparison, EPA—when deciding to approve the ZEV waiver request—referred to CARB's average cost estimate of $500 per vehicle (EPA 2013, 2143). Our comparable estimate using the simulation approach is about $440 per vehicle.

Given that BEVs and PHEVs are powered by immature propulsion systems, indeed potentially disruptive technologies, our estimates of the production costs in 2025 could easily err far on the high or low side. Because cost information about battery packs is proprietary information, the cost-estimation exercise is particularly challenging. Public statements made by suppliers and vehicle-assembly companies about costs may be shaded somewhat to influence debate in the public and private sectors. Here we discuss some of the potential sources of forecasting error in the ZEV premiums.

7.31 Potential Sources of Overestimation of ZEV-Related Costs

We start by considering potential sources of overestimation of the price premium for ZEVs.

1. Lithium ion battery packs are the single most expensive component used in producing BEVs and PHEVs (NRC 2015a; NRC 2015b) but costs are reportedly declining as innovation occurs and scale economies are experienced. If those costs decline faster than the large declines forecasted in the draft TAR (2016), then the ZEV price premiums used here will overestimate the actual premiums experienced by consumers.

2. We have assumed that, in the absence of the ZEV requirements in California and the nine ZEV-aligned states, market forces for BEVs and PHEVs in the U.S. would be minimal. If, instead, market forces—boosted by federal and state subsidies, tax incentives, and non-monetary inducements such as HOV lane access—achieve

significant BEV and PHEV without any ZEV regulation, then the incremental price premiums we are using for the ZEV regulation are too high.

3. The 15.4% BEV/PHEV penetration rate in 2025 is based on CARB's calculation of the number of BEVs and PHEVs necessary to achieve industry-wide compliance with the ZEV requirements. If vehicle manufacturers choose to produce fewer PHEVs (which earn as few as 0.6 credits per vehicle), and produce more long-range BEVs or more fuel-cell vehicles (FCVs) (which earn 4+ credits per vehicle) than predicted in 2025, and if BEVs and FCVs experience unexpectedly large declines in production costs, then the number of BEVs/PHEVs/FCVs required to achieve compliance will be less than expected (Shulock 2016). Thus, the average price premium attributable to the ZEV requirements will be smaller than thought.

4. It is also possible that high-volume vehicle manufacturers, instead of incurring incremental ZEV production costs, will expend accumulated ZEV credits from the pre-2018 ZEV program ("banked" credits) or purchase ZEV credits from other BEV/ZEV producers (e.g., Tesla) to satisfy their regulatory obligations under the ZEV program. If those compliance actions are less expensive than making PHEVs/BEVs, then the price premiums we are analyzing in this report are too high—although large vehicle manufacturers may be vulnerable to public criticism and hostile shareholder resolutions if they do not invest resources in the actual production of BEVs and PHEVs.

5. The ZEV costs assume that buyers cannot recoup some of the energy value of lithium batteries at the end of the battery-life, even though significant energy value will remain for non-automotive applications. Some of the materials, such as cobalt, also have recycled value, though efforts at battery cost reduction are reducing cobalt use in new battery design. Barriers to reusing batteries in non-automotive applications include uncertain degradation rates in second uses; high cost of battery refurbishment and integration; low cost of alternative energy solutions; lack of developed market mechanisms for reuse; and negative perceptions of used batteries (CEC 2015).

6. We have assumed that a 3% ZEV penetration will occur in 2017 in the 10 ZEV states as a result of pre-existing ZEV requirements and other factors. If this 3% figure turns out to be too low (PEVs were about 3% of California sales in 2016 but the share is much smaller in the nine other states), then we have overestimated the incremental compliance cost for the 2018-2025 ZEV requirements.

7.32 Potential Sources of Underestimation of ZEV-Related Costs

Now we consider potential sources of underestimation of the ZEV price premium.

1. If the costs of lithium ion battery packs decline less rapidly than the large declines forecasted in the draft TAR (2016), then the ZEV price premiums used here will underestimate the actual premiums experienced by consumers. In 2015-16, the rate of decline in battery costs appears to have slowed (IEA 2016).

2. NRC (2015a) found that NHTSA (2012a) had underestimated the non-battery costs of plug-in electric vehicles and it is not clear whether the TAR (2016) has adequately addressed the concerns raised by NRC (2015a). If not, the ZEV price premiums we are using may underestimate the actual costs experienced by consumers.

3. The 10 ZEV states vary enormously in their ability to accommodate consumers who purchase a BEV or PHEV. Insofar as states and cities do not invest adequate resources in facilitating commercialization of plug-in vehicles, vehicle manufacturers and dealers will be forced to cut BEV and PHEV prices even further to make them acceptable. In that case, price cuts will need to be financed by even higher prices on non-ZEVs sold throughout the U.S. Under that scenario, the price premiums presented here are too low.

4. The replacement costs for lithium ion batteries will be substantial but the frequency of replacement is unknown. One study assumed that 20% of batteries would be replaced after eight to 10 years of use; the remaining 80% of owners would purchase an entirely new vehicle with a new battery (Commission for

Environmental Cooperation 2015). If those parameters prove to be accurate, the lifecycle costs will be larger (and fuel saving benefits of PEVs will be smaller) than estimated here.

5. Complex issues emerge during the collection phase of spent lithium ion batteries, including which party (battery vs. vehicle manufacturer) holds the liability, and how risks will be allocated for improper management or accidents. Refurbishing lithium ion batteries must be managed carefully as the process can pose safety risks to workers. The associated costs of liability and regulation are not yet known.

6. Procedures for the collection, transportation, disposal, and recycling of spent batteries have not been fully worked out and the associated costs are somewhat unknown. Incentives for recycling are declining due to less reliance on cobalt and other valuable materials in battery design; a long-term net cost of battery recycling is likely (CEC 2015).

7. We have assumed that a 3% ZEV penetration will occur in 2017 in the 10 ZEV states as a result of pre-existing ZEV requirements and other factors. If this 3% figure turns out to be too high (PEVs were about 3% of California sales in 2016, but the share is much smaller in the nine other ZEV states), then we have underestimated the incremental compliance cost for the 2018-2025 ZEV requirements.

7.33 Qualitative Uncertainty Assessment of ZEV-Related Costs

The effect of the ZEV regulation in the ten states on the average prices of new vehicles is quite uncertain. In absolute terms, the uncertainty is less than what exists for the price premium in the federal program because, in 2025, only about 4.6% of the new vehicle fleet (30% x 15.4%) is directly impacted by the ZEV regulation, whereas 100% of the new fleet is covered by the federal programs. In relative terms, however, the degree of uncertainty about the ZEV-related price premiums is greater than for the federal price premiums because (1) it is quite difficult to predict the path of lithium ion battery prices (IEA 2016) reports that the rate of decline in 2015-2016 has slowed), and (2) it is not clear what supportive BEV and PHEV policies (e.g., fiscal and nonfinancial incentives) would be in place in the absence of the 2018-2025 ZEV requirements. However, we could not find a plausible way to put numerical bounds on the unstructured degree of uncertainty.

7.4 The 2016 Perspective: COMET Approach

The previous two sections described how we devised the first two 2016 perspective price premiums, one based on an assumption of high NRC parameter adjustments and the second based on an assumption of low NRC parameter adjustments. We also created a third 2016 perspective based on a formal “bottom-up” technology modeling exercise using the most recent EPA data on vehicle characteristics (TAR 2016).

We first considered using one of the agencies’ pre-existing models, either OMEGA or the Volpe model. Because the models do not include constraints for PEVs that would allow us to capture the ZEV program, we elected instead to recreate the OMEGA model with such constraints. We chose the OMEGA model for replication in order to generate a 2016 perspective based on EPA data, as a complement to the other two 2016 perspective datasets built with NHTSA data. Moreover, the EPA data on vehicle characteristics in OMEGA is more up to date than the RIA-based NHTSA data we used in the 2016 perspectives.

An additional advantage of our adaptation of OMEGA is that it accounts for the cost savings that manufacturers will experience through the federal programs due to the additional cost of offering ZEVs in California and the other nine ZEV states. In other words, since ZEVs have zero tailpipe emissions and offer greater fuel economy than gasoline engines, compliance with the ZEV regulation means that manufacturers can make smaller investments in fuel-saving and GHG-reducing technologies in order for their gasoline engines to achieve compliance with the federal standards (NRC 2015a).

The model, which was constructed by Alan Jenn of the University of California Davis in coordination with the IU research team, has been termed Cost Optimization Modeling for Efficiency Technologies, or COMET. It is an optimization tool that applies vehicle technology packages that improve vehicle fuel efficiency to a fleet of vehicles. The simplified model is built to be flexible with a range of inputs and can incorporate a variety of different policy requirements.

The COMET model minimizes individual automaker cost by choosing the appropriate technology package for each vehicle or vehicle class, while simultaneously complying with regulatory policies. The objective function and constraints are explained in greater detail in Appendix VI.

Since each manufacturer faces a separate set of regulatory requirements (e.g., based on the types and footprint distributions of vehicles produced), COMET is applied individually for each automaker, and therefore, is run 21 times for each of the major automakers in the U.S. The raw output of the optimization model is simply the assignment of technology packages for each of the vehicles included as inputs.

We built a credit banking allowance into the model so that automobile manufacturers can choose to comply with the regulations in later years through the purchase of credits. In order to replicate a credit banking allowance, the cost in a particular year is modified by a discount rate that provides an automaker the ability to shift their costs to later years. For compliance with the federal fuel economy standard, the automaker is not required to meet a hard constraint in each year but rather the total constraint must be met over the entire regulatory period under study.

OMEGA contains a feature that applies a specified vehicle redesign cycle, so that a manufacturer does not need to continually change vehicle packages every year to comply with the increasing standard. Instead, a manufacturer can redesign every several years. (The COMET model does not incorporate this feature.) In order to allow the model to operate continuously and avoid using integer optimization, the redesign cycle was simplified to allow manufacturers to change the application in any given year. It is important to note, however, that the results show that most vehicles are not re-designed every year. The credit banking allowance described above helps maintain this flexibility in technological choices across time.

The OMEGA model also included a “fleet protection” feature that controlled mass reduction and safety class. Similar to the cycle redesign, we elected to not include this feature in COMET in order to simplify model computation.

7.41 Input Data and Constraints

We run the COMET model using EPA OMEGA input data, and make modifications to these data, to account for the 2016 perspective. Data inputs for the COMET model include (1) market data such as manufacturers, volume of vehicle sales, vehicle characteristics (including recent forecasts of the likely mix of light trucks vs cars), (2) technology data such as technology package descriptions, costs, technology application ranking factors based on cost, reduced fuel opportunity, and fuel efficiency improvements, and (3) equations with which to comply, as are presented in Appendix VI. The majority of the data inputs used to run the model are from various applications of the EPA’s OMEGA model. In particular, we rely on input data OMEGA 1.4.1, which was the dataset used in the 2012 EPA Regulatory Impact Assessment, and OMEGA 1.4.56, which was the dataset used in the TAR (2016).

The market data consists of the full list of automakers regulated under the CAFE and GHG standards. The market data are then broken down by vehicle category (i.e., car or truck), vehicle class and model, average vehicle emissions rate, average footprint, and annual expected sales. In addition, each vehicle is classified by two indices to track the category and class/model, which can then be matched to the suite of technology packages.

The vehicle sales provided in both OMEGA v1.4.1 and OMEGA v1.4.56 are estimated annual sales that are repeated for the years under analysis. Thus, the sales from year to year are identical, but the technology applications are not. A different set of exogenous inputs can be applied to vary the sales based on external assumptions, but the vehicle sales are not endogenous to the model.

It is important to note that the EPA revised their estimates of total vehicle sales, and the distribution of sales between cars and trucks, between the v1.4.1 and the v1.4.56 versions. In the v1.4.1 version of the dataset, total vehicle sales between 2017 and 2025 are assumed as approximately 92 million cars and 51 million trucks. In the v1.4.56 version of the dataset, total car sales over this same period of time are assumed to be 59 million and total truck sales to be 85 million. This switch in the distribution of cars to trucks has important implications in our macroeconomic modeling of gas savings, as we will discuss in the next section.

Each vehicle class/model has an affiliated "technology type" index that maps a possible set of technology packages that can feasibly be added to an existing vehicle. These packages are obtained from both OMEGA v.1.4.1 and v.1.4.56 input files. Each package has several attributes associated with it: a percentage cap, identifying the maximum proportion of vehicles that the technology package can be applied to; efficiency improvement, the percentage increase in efficiency resulting from the use of the technology package; and incremental cost, the cost of installing the technology package. Additionally, the technologies are pre-ordered by efficiency and cost through the EPA's technology application ranking factor, which allows the optimal package to be chosen by simply going down the list of technologies for each vehicle class/model.

For vehicle fuel technologies, OMEGA v.1.4.1 does not include PEV technologies in their input and output files. Therefore, to model both the CAFE/GHG standards and the ZEV standards, it is necessary to use the OMEGA v.1.4.56 dataset. In OMEGA v.1.4.56, the technology files include a range of pure electric drivetrains at 75-, 150-, and 200-mile ranges (BEVs). There are no technology packages included for PHEV drivetrains, although the default market inputs include several PHEV models such as the Chevy Volt. The presence of PHEVs is therefore a function of currently existing models that have the drivetrain installed, but it is not possible for the technology to be included in any vehicle models in the future.

Some of the inputs from OMEGA v.1.4.1 are modified by updating values to match estimates from NRC (2015a). The various scenarios that use OMEGA v.1.4.1 data are run at a low bounds assumption that matches the assumptions used in the EPA RIA (2012a), and at a high bounds assumption based on those NRC estimates that we were able to match across the NRC report and the OMEGA v.1.4.1 input data. In the high scenarios, for example, these technologies include the following (the additional dollar value added to the technology to match the NRC estimates are included in the parentheses):

- Dual Cam Phasing (+$9)
- Discrete Variable Valve Lift (+$15)
- Integrated Starter Generator (+$130)
- 6-speed automatic (+$153)
- 8-speed automatic (+$68)
- Turbocharging and Downsizing (18 bar BMEP) (+$38)
- Stop Start (+$50)
- Strong Hybrid (Power Split System) (+$500)
- Vehicle Integration (NVH, Thermal Management) (+$25)

We were able to match approximately 76% of the technologies across the NRC report and the OMEGA input database. We were unable to match all technologies because the NRC estimates of fuel-saving effectiveness and technology cost were based on the NHTSA data and technology classifications, and not on the EPA data. We were also unable to incorporate NRC estimates of fuel-saving effectiveness into the COMET modeling. Thus, the resulting fleet-wide cost estimates obtained from the cost optimization model are likely lower than they would be if we were able to match all NRC parameters within our OMEGA v.1.4.1 input dataset.

7.42 Model Results

There are two primary sets of scenarios run by COMET: one using the OMEGA v1.4.1 data inputs used in the RIA for CAFE/GHG standards and the other using the OMEGA v1.4.56 input files used in the draft TAR (2016).

The baseline scenario assumes that the CAFE and GHG emissions standards ramp up until 2016 and are then held constant thereafter. With the OMEGA v1.4.1 data, we run a scenario in which the standards rise to their 2025 levels (scenario 1), and a second scenario that matches the first but has revised technology cost parameters based on NRC suggestions and outlined above (scenario 2). We then replicate this same federal standard using the OMEGA v1.4.56 dataset which, again, is what EPA used in the draft TAR (2016) (scenario 3). None of the first three scenarios, therefore, include the ZEV standard, which we subsequently introduce in scenarios 4 and 5. With the OMEGA v1.4.56 data, we run a scenario in which the federal standards increase up through 2025 and the ZEV standard also increases up through 2025 (scenario 4). We also run an additional scenario in which we introduce the federal GHG standard multiplier for PEVs and FCVs, and have built in the ability to count these vehicles as zero-emitting (scenario 5). Assumptions about the multiplier and emissions credit match the policy design, as outlined in section 3.3. All scenarios have a base vehicle year of 2014.

The resulting average price premium per vehicle is presented in Table 7.10, along with information about which dataset the scenario used and the exogenous specification of total car and truck sales. As these data reveal, we were able to replicate the original (EPA 2012a) price premium results from their OMEGA model quite well for scenario 1, with less than a $100 difference in the year 2025. Adding the NRC parameter adjustments (scenario 2) does not significantly increase the resulting price premium values, likely due to some mismatch between the NRC technology categories and those contained within the OMEGA v1.4.1 dataset, perhaps because NRC fuel-saving effectiveness estimates could not be incorporated, and that NRC adjustments were based on NHTSA data.

The price premium results in scenario 3 using OMEGA v1.4.56 data are lower than in scenarios 1 and 2, as well as in the NRC suggested adjustments to the NHTSA 2012. These results are due to the model inputs, which are (1) based on EPA data, where EPA and NHTSA are not completely identical, and (2) based on data that EPA updated when working on the draft TAR (2016).

For example, EPA now includes data on a relatively new, cost-effective Atkinson engine that NHTSA and NRC did not include in their list of commercially likely innovations. In its most recent proposed determination on

Table 7.10. Average Price Premium per Vehicle Due to Specified Regulations Based on COMET 2016 Perspective Scenarios

Scenario	Input Data	Vehicle Sales 2017-2025	2017	2018	2019	2020	2021	2022	2023	2024	2025
Scenario 1: EPA GHG standards through 2025	v1.4.1	92,044,659 cars and 50,715,137 trucks	$137	$282	$491	$697	$907	$1,150	$1,383	$1,566	$1,760
Scenario 2: EPA GHG standards through 2025; some NRC adjustments	v1.4.1	92,044,659 cars and 50,715,137 trucks	$265	$404	$603	$813	$1,027	$1,269	$1,500	$1,672	$1,881
Scenario 3: EPA GHG standards through 2025	v1.4.56	59,348,125 cars and 84,652,992 trucks	$56	$203	$362	$489	$599	$706	$847	$1,046	$1,249
Scenario 4: EPA GHG standards through 2025; ZEV standards through 2025 (referred to as "2016 Perspective COMET" in this analysis)	v1.4.56	59,348,125 cars and 84,652,992 trucks	$80	$216	$471	$707	$899	$1,085	$1,293	$1,550	$1,821
Scenario 5: EPA GHG standards through 2025; ZEV standards through 2025; includes GHG standard multiplier and emissions credit	v1.4.56	59,348,125 cars and 84,652,992 trucks	$67	$202	$447	$684	$889	$1,077	$1,277	$1,527	$1,798

the 2022-2025 standards, EPA adjusted downward the penetration rate of this new engine in conjunction with other technology adjustments (EPA 2016a; TAR 2016). Since this issue is now in a public comment process and is likely to remain controversial through the development of forthcoming RIAs, it may be some time before the issue is properly handled.

When we introduce the ZEV standard in scenario 4, the price premium rises above those values for only the federal standards. In 2025, the premium is almost $600 more expensive per vehicle with both the state and federal standards than if just the federal standards were in place, after accounting for the savings manufacturers experience in the federal programs.

The $600 figure is larger than the comparable $440 figure we estimated based on the simulation using TAR (2016), CARB, NHTSA, EIA, and DOE data. One of the possible contributors to the $160 per vehicle difference is that the baseline rate of ZEV penetration in 2017 was 3% of all light-duty vehicles in our simulation approach but was smaller in the formal COMET model (2.1% for cars and 0.8% for trucks). We have chosen to use the COMET-derived ZEV premium in the macroeconomic modeling for a conceptual reason: it accounts for the compliance interactions between the federal and ZEV regulations while the simulation approach does not. We refer to this scenario as the 2016 COMET Perspective from here on out.

Scenario 5 also combines the state and federal standards, and additionally provides a bit more nuance into the ways in which these policies could interact. More specifically, scenario 5 introduces the federal GHG multiplier and GHG credit provisions for electric and fuel cell vehicles. Since these two provisions should make it easier for auto companies to comply with the GHG standards, we should observe a decline in the price premium relative to scenario 4, as we witness to be the case in Table 7.10.

Although there are some limitations to the results of our COMET modeling—primarily our inability to perfectly match all NRC parameters with the simplifications that we made to the model for computational ease—the key advantages of the COMET-based results are that they (1) capture some of EPA's technical perspectives on the issues of fuel-saving effectiveness and technology cost, (2) are based on the most up to date information on vehicle characteristics, (3) are based on the most up to date information on the costs of BEVs, and (4) capture the interaction of the federal and ZEV programs in the choices made by individual vehicle manufacturers.

7.5 Summary of 2012 and 2016 Perspective Datasets used in Macroeconomic Modeling

In sections 8 and 9, we present our macroeconomic results, using much of the input data we have just described. The distinction between sections 8 and 9 is that section 8 focuses on the economy as a whole (employment, GDP, and income, as simulated through a macroeconomic model called REMI, which we define in the next section) whereas section 9 presents more specialized analyses of consumer demand for new vehicles based on total cost of ownership (TCO) modeling.

Table 7.11 lists all the datasets that will be used in sections 8 and 9 along with a description of their key characteristics. The table also serves as a way to distinguish between how the various datasets are considered in the REMI vs. TCO modeling. The main differences pertain to a series of parameters—resale value, consumer fuel price projections, number of years of fuel savings valued by consumers, and vehicle miles traveled—that are considered in the TCO but not in the REMI model. Additional parameters that are considered by the TCO but not the REMI model (and do not appear in Table 7.11 as they have less of an effect on car sales) are sales taxes, auto-loan financing costs, and auto-insurance costs. National gasoline savings from the regulatory programs, as used in the REMI modeling, are not all based on the same data. In particular, for the 2012 and 2016 perspectives that rely on NHTSA data, national fuel savings are based on vehicle sales data reported in NHTSA's 2012 RIA. For the 2016 COMET perspective, the national fuel savings are based on vehicle sales data from the 2016 draft TAR. For the REMI modeling in section 8, where national estimates of gasoline savings play a crucial role, it is useful to remember that the COMET 2016 dataset has a much larger mix of light trucks relative to cars from 2017-2035 than is assumed in all of the other datasets.

Table 7.11. Distinction between REMI and TCO Datasets

Model	Dataset	Price Premium	ZEV Regulation	Resale Value	Consumer Fuel Price Projections	Years of Fuel Savings Valued	VMT
REMI	2012 EPA Perspective	EPA 2012 RIA	Not included	N/A	N/A	N/A	N/A
TCO	2012 NHTSA Perspective	NHTSA 2012 RIA	Not included	35% of premium	AEO projections	5	NHTSA 2012 RIA
REMI	2012 NHTSA Perspective	NHTSA 2012 RIA	Not included	N/A	N/A	N/A	N/A
TCO	2016 High Perspective	NHTSA 2012 RIA + high NRC adjustment + ZEV (TAR data on battery costs as reviewed in section 7.3)	BEV200, BEV100, PHEV10 & PHEV40	35% of premium	Tomorrow's fuel price equal to today's fuel price	3	NHTSA version in TAR 2016
REMI	2016 High Perspective	NHTSA 2012 RIA + high NRC adjustment + ZEV (TAR data on battery costs as reviewed in section 7.3)	BEV200, BEV100, PHEV10 & PHEV40	N/A	N/A	N/A	N/A
TCO	2016 Low Perspective	NHTSA 2012 RIA + low NRC adjustment + ZEV (DOE data on battery costs as reviewed in section 7.3)	BEV200, BEV100, PHEV10 & PHEV40	35% of premium	Tomorrow's fuel price equal to today's fuel price	3	NHTSA version in TAR 2016
REMI	2016 Low Perspective	NHTSA 2012 RIA + low NRC adjustment + ZEV (DOE data on battery costs as reviewed in section 7.3)	BEV200, BEV100, PHEV10 & PHEV40	N/A	N/A	N/A	N/A
TCO	2016 COMET Perspective	Estimated via the COMET model with updated technology costs and the ZEV standard (as reviewed in section 7.4)	COMET only selects BEV75 since it is the cheapest type of ZEV	35% of premium	Tomorrow's fuel price equal to today's fuel price	3	NHTSA version in TAR 2016
REMI	2016 COMET Perspective	Estimated via the COMET model with updated technology costs and the ZEV standard (as reviewed in section 7.4)	COMET only selects BEV75 since it is the cheapest type of ZEV	N/A	N/A	N/A	N/A

Note: This table highlights some of the main differences between the way the datasets are defined for REMI and Total-Cost-of-Ownership (TCO) models. The main difference is that the TCO accounts for consumer valuation of fuel savings. In addition to the differences highlighted here, the TCO definitions also include sales taxes, auto-loan financing costs, and auto-insurance, which are not factored into REMI. All of the 2012 perspectives use fuel price projections from the AEO 2012 while the 2016 perspectives use AEO 2016 projections. Other variables such as vehicle miles traveled, survival rate, fuel price projections, and fuel economy are similar between the two models; they enter the TCO directly and REMI indirectly through fuel savings. TAR is technical assessment report, DOE is Department of Energy, RIA is regulatory impact analysis, ZEV is zero-emissions vehicle, BEV is battery electric vehicle, PHEV is plug-in hybrid electric vehicle, NRC is National Research Council, and N/A is not applicable.

8. EVALUATING IMPACTS ON EMPLOYMENT, GDP, AND INCOME

We now turn to our modeling of the impacts of the federal and California standards on employment, GDP, and real disposable income. Changes in the levels of these three standard macroeconomic indicators are watched closely by policy makers, stakeholders, investors, and Wall Street and corporate analysts.

Our objective for this macroeconomic modeling is to simulate the national and regional economic impacts of the federal and California standards. We do so from both the 2012 and 2016 perspectives, using the five datasets described previously. We begin with a statement of theoretical expectations, then describe our modeling platform, present the details about the inputs that were used to generate the results, and present our analytic results. We conclude with a discussion of uncertainties and promising future research directions.

As we present our results, we urge the reader to consider that macroeconomic impacts, though obviously important, are not the only impacts of the federal and California regulations. The results presented here do not account for environmental impacts, such as climate-related emissions of greenhouse gases or pollutants related to local levels of smog and soot. Nor does our analysis provide an overall cost-benefit analysis of the regulations from a societal perspective.

The scope of our analytic work is specialized and focused, seeking to determine how technology costs and fuel savings, largely through private-market channels, may impact the U.S. economy (nationally and by region) as a whole in the years ahead. Thus, we urge readers to consider our results in conjunction with other kinds of analyses (e.g., environmental, and cost-benefit analyses) that are informative for regulatory policy making.

8.1 Macroeconomic Theoretical Expectations

We postulate that the macroeconomic impact of the regulatory programs occurs as if the U.S. economy were subject to both a tax increase on new vehicle sales (CBO 2004; Jacobsen and van Benthem 2015) and a tax cut expressed in the form of savings in gasoline expenses, perhaps similar to what might result from a reduction in the gasoline tax (Morath 2014; Arora 2015). The tax increase is more immediate, since it is reflected fully in the prices of new cars and light trucks (or the somewhat deferred payment of car loans), while the tax cut is more gradual but grows in magnitude as fuel savings accumulate over the 30-year maximum lifetime of a cohort of cars (37 years for trucks). We do not model how the rise in new vehicle prices ripples through used-vehicle markets, though that would be a useful extension for future work (Jacobsen and van Benthem 2015).

Unless one suspects different macro effects depending on the type of tax, the long-run effect on the U.S. economy is determined by the relative magnitude of the tax increase compared to the magnitude of the tax cut. Since the federal agencies estimated in 2012 that the vehicle price effects of the 2017-2025 standards are small compared to the present discounted value of the fuel savings, we expect the 2012 perspective to show that the federal programs exert a long-run positive impact on the U.S. economy.

If the regulatory programs applied to only one model year of vehicles, then the impact on the U.S. economy after year one would depend on the size of the vehicle price increase compared to the size of the fuel savings in the first year. In the second year, assuming that there is no additional price increase, there would now be two years of fuel savings offsetting the initial price increase. Those fuel savings continue to accumulate each year, though at a decreasing rate, as vehicles in the initial cohort age, are driven less, and are removed from the fleet.

If the vehicle price increase is larger than the fuel savings in the first year, as the 2012 NHTSA and EPA RIAs suggest is the case, then the interesting question is how long it will take for the fuel savings to overtake the initial price premium increase. When we add the complication of a rising price premium due to a schedule of stricter standards from 2017-2025, the same temporal question presents itself, assuming that each incremental rise in the price premium is ultimately overwhelmed in magnitude by future fuel savings. How long will it take for the economic impacts of the schedule of price increases to be overwhelmed by the accumulated savings in gasoline expenditures? We seek to answer that question using data from 2012 and 2016.

As the economic impact of the vehicle price increase is modeled, we are careful to consider that the impact on the U.S. economy (e.g., employment, income, and output) will not be entirely negative. Higher prices for new vehicles fund economic activity in the automotive supply chain. Fuel-saving technologies such as turbochargers, stop/start systems, and lithium ion batteries are being added to vehicles, and those investments in innovation have positive employment, output, and income effects (Baum and Associates 2016). We expect that those stimuli arising from a vehicle price increase will offset, at least to some degree, the adverse effects of increased vehicle price premiums on consumers.

Given the uncoordinated interaction of the ZEV program with the federal programs, the ZEV program acts as a tax increase on new vehicle sales without any offsetting tax cut for the average consumer (i.e., the purchaser of the PEV saves fuel but the average new-vehicle consumer in the U.S. does not save fuel due to the PEVs produced under the ZEV regulation). We discuss this uncoordinated interaction issue in more detail in section 10. From a macroeconomic perspective, the ZEV program prompts an interesting dynamic change in the automotive supply chain: the replacement of internal combustion engines with batteries and electric drivetrains. Although we do not formally model the impacts of this shift in the supply chain, we examined this dynamic qualitatively in section 3.

8.2 Modeling Platform

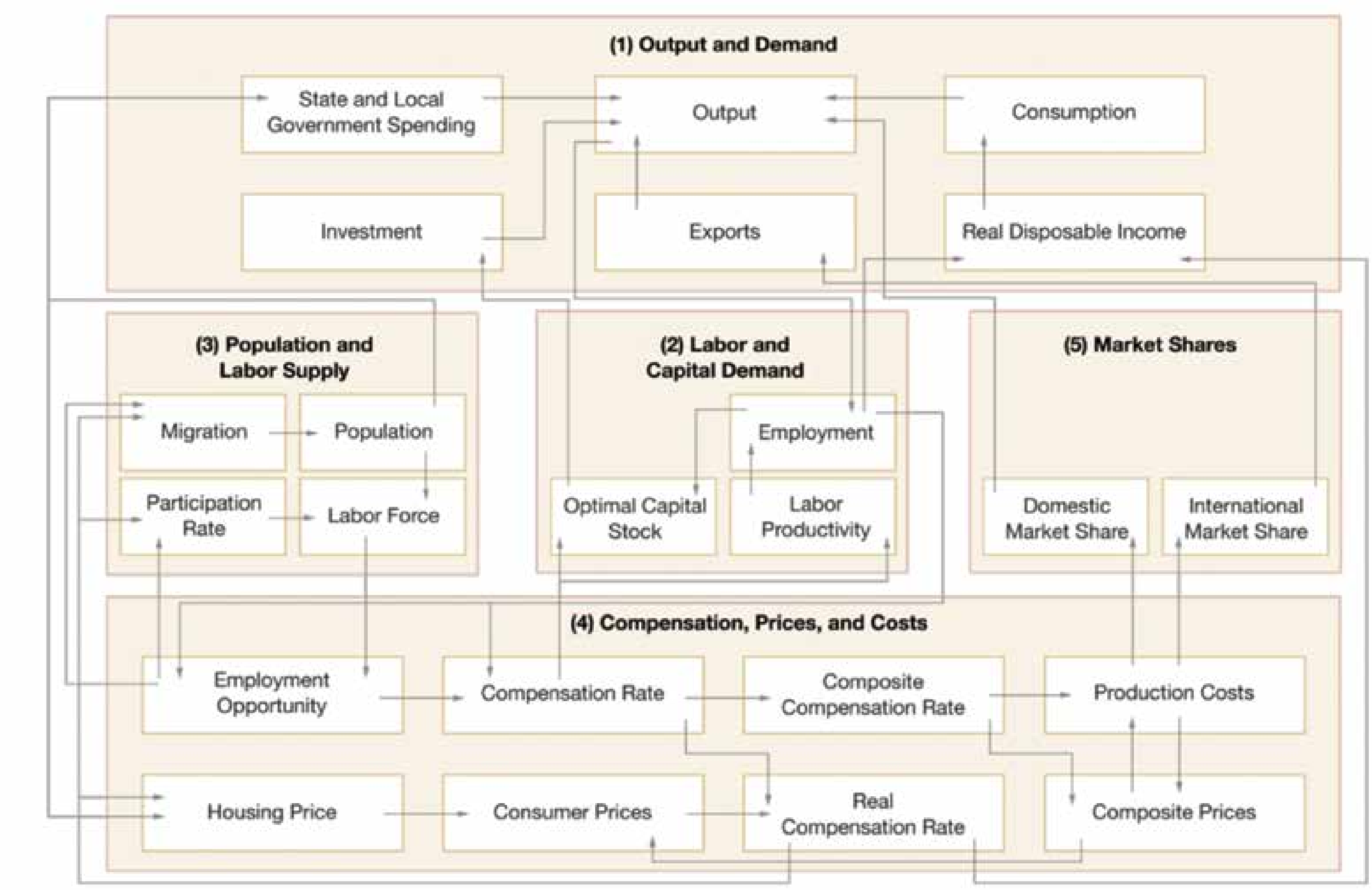
The tax increases and decreases we are modeling will have ramifications beyond the automotive and energy sectors. For each loss or gain in new vehicle production, there are ripple effects that occur throughout the supply chain for vehicles, sometimes referred to as "backward linkages" (PwC 2013; The Perryman Group 2014). A change in the demand for new vehicles changes the demand for steel, which in turn changes the demand for iron ore and coal. Likewise, when consumers save money on gasoline, there is a consumer reallocation effect, which means households have more income to spend on other goods and services such as eating out at restaurants, outdoor recreation, and consumer electronics. The supply chains of these sectors are in turn stimulated indirectly when consumers save money on gasoline.

The tools of input-output analysis were devised in the 1930s and 1940s, building on the theoretical work of Nobel Laureate Wassily Leontief (Leontief 1986). These tools were devised to help characterize and quantify the interactions between different sectors of the economy, and they are now commonplace in economic analysis (BEA 2009). A variety of modeling platforms are available to capitalize on the growth in understanding about how sectors of the economy are interconnected.

The modeling platform that we use to simulate the macroeconomic impacts of the regulations on the national economy is REMI PI+ 2.0.2, as constructed by the Regional Economic Models, Inc. PI+ is a dynamic structural economic forecasting and policy analysis model. It combines input-output, computable general equilibrium, econometric, and economic geography modeling components. The model contains thousands of different simultaneous equations pertaining to output and demand, labor and capital demand, population and labor supply, prices and costs, and trade ratios. The interactions among these categories in the REMI model is presented in Figure 8.1.

Following the introduction of the REMI model (Stevens et al. 1983) and subsequent additions to the model (Fan, Treyz, and Treyz 2000), it has been used extensively by researchers. The peer-reviewed literature has employed the model to analyze regional clean air incentives markets (Johnson and Pekelney 1996), business incubator outcomes (Sherman and Chappell 1998), development benefits of highway decision making (Weisbrod and Beckwith 1992), economic impact of retirement migration (Deller 1995) and economic benefits of environmental management at U.S. nuclear weapons sites (Frisch et al. 1998). The grey literature has used the model to analyze the future availability of family caregivers (Redfoot, Feinberg, and Houser 2013), solar power generation in Nevada (Schwer and Riddel 2004), economic impact of the Mashantucket Pequot tribal nation operations in Connecticut (Carstensen et al. 2000) and highway congestion (NHCRP 2001).

Figure 8.1. REMI Model Linkages.



The REMI model can be run at different geographical levels and with varying degrees of economic sector granularity. For this project, we use a 160-industry-sector, 9-region version of the model. These nine regions, as delineated in Figure 8.2, correspond to the Census Bureau's nine major divisions of the U.S.

We present results for three different economic indicators: employment, gross domestic product (GDP), and real disposable personal income. As also used by the U.S. Bureau of Economic Analysis, the employment output captures full-time, part-time, and sole proprietors. Employment is a stock concept, meaning that it should not be aggregated over time but instead interpreted in a single year relative to a base year. GDP accounts for all business transactions minus demand for intermediate goods and services. Thus, this output only reflects net new economic activity. Real disposable personal income captures the change in after-tax real income.

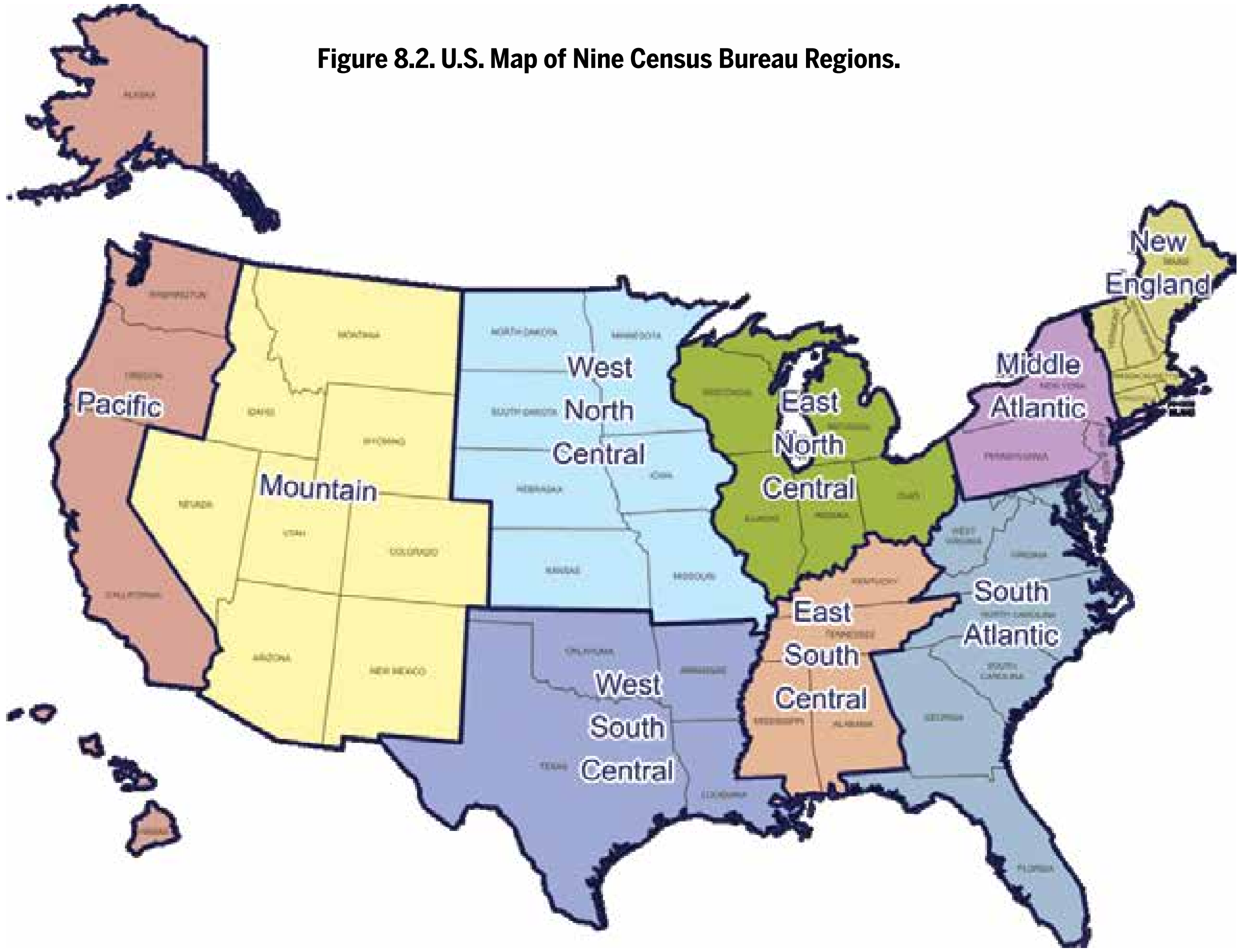
8.3 Constructing Policy Mechanisms in REMI

The federal CAFE/GHG and California ZEV regulations affect the U.S. economy through several mechanisms. We begin by describing each mechanism separately and then explain how the mechanisms are combined to model the overall impact of the regulations. It is important to consider each aspect separately, since each has its own set of input assumptions and also affects the economy in different ways.

8.31 Vehicle Price Premium

In order to capture the impact of the vehicle price premiums associated with the regulations, we began by dividing vehicle consumers into two categories: those that purchase vehicles for personal use and those that purchase vehicles for use in private (i.e., industry or commercial) or government fleets. We assume that 80% of vehicle

Figure 8.2. U.S. Map of Nine Census Bureau Regions.



Source: United States Regional Economic Analysis Project, available at https://united-states.reaproject.org/

purchases are for individual consumers, 19% are private industry fleet purchases (e.g., rental car agencies and corporate fleets), and the remaining 1% is for government fleet purchases. This distribution is based on historic vehicle sales data, as gathered by Polk (2016), and on the registration category breakout outlined by Polk (2002). The regional distribution of sales are allocated to the nine Census regions in proportion to total light-duty vehicle sales, as specified by the EIA (2012).

For consumers, the total additional expenditures on light-duty vehicles due to the regulations are treated as an automobile price increase. For government, the additional expenditures are treated simply as additional government spending on automobiles. For private industry, the additional expenditures are operationalized as additional production costs, and spread across 160 sectors according to the amount of total light-duty vehicle transportation-related GDP output each sector accounts for.

8.32 Automobile Supply Chain Reinvestment and Technological Innovation

Increased expenditures on vehicles pay for economic activity, which occurs originally in the supply chain of the automotive sector (Baum and Associates 2016). We frame this activity as investment in technological innovation and deployment, since that is the functional purpose of the regulations. Like any form of economic activity, the supply-chain investments due to regulation stimulate employment, output, and income.

We assume that 100% of the vehicle price premium is translated into spending in the automobile industry sector, but a certain percentage of that stimulus will occur entirely outside of the U.S. economy (Hagerty and Bennett 2015). For example, all of the global automakers, including the Big Three, are allocating a significant share of new investments to China and other emerging markets, especially India, Southeast Asia, and Latin America. The forecasted rate of growth in new vehicle demand is higher in these regions than it is in North America and

Europe (Greimel 2016). Within North America, about 65% of new automotive (OEM) facility investments are being allocated to the U.S., with Mexico's share rising, the U.S. share declining, and the Canadian share stable (CAR 2015; Swiecki and Menk 2016; Boudette 2016).

Since the leakage of stimulus spending outside the U.S. reflects strategic decisions of specific manufacturers, it has been suggested that descriptor variables of manufacturers may have explanatory power, at least as surrogates. The most common variables that have been suggested for consideration are the location of the company's global headquarters, whether the company has R&D centers in the U.S., whether the company assembles its vehicles in the U.S., whether a company assembles its engines and/or transmissions in the U.S., and the domestic content of the parts used in a company's vehicles (Burroughs 2013). We are aware of no statistical data showing how each of the descriptors of manufacturers relate to the probability that a dollar of revenue from the U.S. market will be reinvested in the U.S.

A recent study of Toyota's operations provides significant evidence that investments may occur in the U.S. even though the company's global headquarters are located outside of the country and they make extensive use of non-U.S. companies in its supply chain (Dziczek, Chen, et al. 2016). The leadership of Toyota's North American operations was recently consolidated and moved from Torrance, California, to Plano, Texas. The company currently has seven North American assembly plants: four in the U.S., two in Canada, and one in Mexico. Plans for a new assembly plant in Guanajuato, Mexico, were recently announced. A majority of the Toyota cars and light trucks sold in the U.S. are currently assembled in the U.S. Toyota also has three engine plants and a dedicated transmission plant in the U.S. In recent years, Toyota has been a net exporter of engines from the U.S. to the rest of the world. In terms of R&D, Toyota has 11 identifiable centers or institutes in the U.S. with different foci, three of which have formal linkages to U.S. universities (Stanford, MIT, and the University of Michigan). Over the last decade (1996-2015), Toyota's new investments in North America have been distributed 66% in the U.S., 23% in Canada, and 11% in Mexico.

Information on the U.S. orientation of other global automakers is less well documented. In section 3 we showed that the Japanese OEMs and their suppliers and dealer networks are well integrated into the U.S. economy. Honda, for example, launched the first assembly plant in the U.S. in the 1980s (Ohio) and currently has 14 R&D facilities in the U.S. (Honda 2017). Volkswagen is known as the global leader in auto-related R&D spending but most of that spending does not occur in the U.S. (Sharman 2014).

To simplify a complex issue, we assume that 30% of all investments by OEMs (excluding investments by parts makers) will occur outside of the U.S. That figure may seem low, since the U.S. market share of the Big Three in 2015-2016 was only 45.3%. Insofar as Toyota is treated more like the Big Three than like the other global automakers, with respect to investment interest in the U.S. market, the U.S.-related market share rises from 45.3% to 59.5%. Adding in Honda (9.2%) ups the total from 59.5% to 68.7% (Wall Street Journal 2017). We maintain the 30% assumption in the 2012 and 2016 perspectives but we also run a series of sensitivity analyses using different percentages.

The uncertainty here is partly related to policy. There is growing pressure on OEMs from U.S. politicians to reinvest revenues from the U.S. market in the U.S. automotive sector. The recent disputes between the new Trump administration and automakers over investments in Mexico are a microcosm of a much larger policy uncertainty.

REMI also assumes regional purchase coefficients in auto industry supply chains of approximately 70%, plus or minus depending on the specific supply chain. In other words, REMI assumes that for each dollar invested in the U.S. auto supply chain, approximately 70 cents stays in the U.S. economy. This estimate matches the U.S. Department of Commerce's Economics and Statistics Administration's finding that, of all domestically-produced motor vehicles and parts, the average domestic content is 71% (DOC 2014).

The 70% of the OEM reinvestment that stimulates the U.S. economy is allocated in several categories of economic activity: 4% goes toward research and development (R&D), 7.8% toward increased production in labor, 32.1%

toward increased production of motor vehicle parts manufacturing (i.e., materials), 39.1% toward overhead and management, 7.1% toward shareholder income, and 9.6% toward auto dealership income. All of these mechanisms affect only the automobile industry (i.e., NAICS codes 3361, 3362, and 3363). Appendix VII provides a detailed explanation of how those percentages were derived.

In the REMI model, regulation is modeled as increasing investment in R&D by increasing industry sales for scientific research and development services. The increase in labor is modeled as an increase in industry sales for motor vehicle manufacturing. Materials are modeled through motor vehicle parts manufacturing. The increase in overhead is entered into the model through industry employment for management of companies and enterprises. Shareholder income is operationalized as proprietor income in the auto industry, and dealership income is operationalized as automobile dealership income.

8.33 The Gasoline Savings Mechanism

Savings in gasoline expenditures again operate through the same three categories of consumers: individual consumers, government fleet consumers, and private industry fleet consumers. All three groups of consumers are modeled as saving money on gasoline expenditures but are then subject to a macroeconomic balancing mechanism in which they spend an equivalent amount on all other goods and services, since savings and debt are held constant in REMI.

For consumers, expenditures on gasoline are operationalized in REMI through a decrease in consumer spending on motor vehicle fuels, lubricants, and fluids. Since consumers retain the extra money that would have been spent on gasoline, they ultimately spend this money on other goods and services, which is entered into the model as a consumption reallocation to other goods and services. For industry, we enter gas savings in REMI as a production cost decrease, and those savings are spread across all industry sectors, according to their shares of transportation-related GDP. Similar to individual consumers, the government spends less on fuels, lubricants, and fluids, but has more money available for other types of expenditures. It is important to note that taxation and deficit spending are held constant (Appelbaum 2016; Conoscenti 2011).

The reduced consumption of gasoline is expected to reduce U.S. demand for oil, which in turn reduces oil imports and U.S. oil production. REMI is structured to generate a 50-50 split in the relative impact on importation vs U.S. production of oil, and we assume that there is no change in that distribution throughout the time horizon of the study. As U.S. oil production changes, there are ripple effects throughout the energy supply chain such as changes in refining activity, oil and gasoline transport, purchases of equipment for exploration and development, and sales at wholesale and retail gasoline outlets.

In the public debate on CAFE, the argument is sometimes made that the gasoline savings from CAFE have no net impact on the U.S. economy because, in effect, the economy does not respond differently from a dollar spent on gasoline (oil) and a dollar spent on other goods and services in the economy (Appelbaum 2016). This assumed dollar-for-dollar equivalence is not consistent with the findings of input-output models where the multiplier effects in the supply chains of different sectors are quite different, in part due to differences in sector-specific import ratios in the supply chains. For example, in section 3 we reviewed a recent study showing that, for each job gained or lost in the assembly of new vehicles, another 7 jobs are gained or lost in parts production and in other sectors of the U.S. economy (CAR 2015). Similar studies of the U.S. oil and gas sector (by different authors but with similar input-output methods) found that each job gained or lost in U.S. oil and gas extraction is associated with another 2.7 to 3.5 jobs gained or lost in the U.S. economy as whole (PwC 2013; Conoscenti 2011). Thus, the net effects of gasoline savings on the U.S. economy require formal modeling, and cannot be assumed to be neutral based on first principles.

8.4 Time Horizon for the Analysis

Our modeling compares the combined impacts of the federal and California standards for model years 2017-2025 to a baseline scenario where the federal standards are frozen at their 2016 levels and the California ZEV standard is frozen at its 2017 level. The theoretical time horizon is long, through 2055 or 2060, since some of the new vehicles produced in 2025 (and their design-based impact on the economy) will last for more than 30 years.

For practical reasons, we report results for the period 2017-2035, since the underlying assumptions, inputs, and forecasts are more plausible for the shorter time horizon, and because intervening policy, technological, and economic variables can change in unexpected ways as the time horizon is lengthened by decades. On the other hand, the time period through 2025 is too short to fully reveal the powerful impact of gasoline savings on the U.S. economy. Fuel-efficient vehicles produced in 2025 will save some gasoline in their first year of operation but a disproportionate share of gasoline savings will occur over the initial 10 years of use, when vehicle miles of travel are relatively high and rates of vehicle scrappage are low. Consequently, the impact of the 2025 standards on the U.S. economy will have both a short run and long run effect, with temporal trends apparent by 2035. In a few exceptional cases where we found important trends after 2035, we discuss them in the text.

8.5 Summary of Modeling Results

We begin by presenting the results of the "tax increase" effect: the rise of vehicle price premiums and their impact on employment, GDP, and real disposable income. We then consider the reinvestment/innovation effect of the price increase, as the supply chain is stimulated, to provide more fuel-saving technologies. We finally consider the "tax cut" effect: the savings in gasoline expenditures that permit consumers to shift from purchasing gasoline to purchasing other goods and services in the economy.

All graphs presented in this section reflect the difference between the baseline scenario—in which federal standards do not rise above 2016 values and ZEV standards do not rise about 2017 values—and the policy scenario of interest. In the case of the 2012 perspective, the scenarios measure the difference between federal standards staying at 2016 levels and fuel economy standards rising to 2025 levels. In the 2016 perspectives, the policy scenario also includes the ZEV standard (technically, the ZEV regulation under study begins in 2018 and extends to 2025).

8.51 The Vehicle Price Effects

Within REMI, when vehicle production costs increase, prices rise for new motor vehicles. Consumers pay higher prices for these vehicles, which is entered into the model as an increase in consumer price for new motor vehicles. An increase in consumer price causes a decrease in the real compensation rate of households, since overall prices in the economy are higher for the same level of compensation. Real disposable income decreases due to higher consumer prices. Because of decreased real disposable income, consumption decreases and this causes output to decrease. The effect of the increasing consumer price causing real compensation and consumption to decrease is a variant of the well-known income effect (the change in consumption from a change in real income).

The other mechanism at work in REMI is the price elasticity effect: the lowered consumer demand for vehicles due to the higher price of new motor vehicles. Both the income and substitution effects work together to result in a decreased demand for new motor vehicles.

The increase in consumer price of new motor vehicles affects output of the automotive industry the most. But, with any increase in consumer price, industries such as construction, retail trade, wholesale trade, and real estate also experience decreases in output.

The increase in government expenditures on vehicles in REMI causes the amount of money available to spend elsewhere to decrease. As a result, there is a decrease in government spending. Government spending is also affected by changes in gas savings and operations and maintenance expenditures, as we discuss in more depth below.

A decrease in government spending causes output to decrease, which causes employment to decrease. The decrease in employment affects real disposable income and consumption, both of which decrease and subsequently cause output to decrease. The other effect of decreasing employment is that it causes the optimal level of capital to decrease, and thus there is a decline in investment. This also affects output negatively.

For private industry, higher vehicle costs translate into greater production cost. Increases in private industry expenditures on vehicles cause an increase in the cost of creating output, or production cost. The production cost increase is weighted by the amount of intermediate inputs associated with transportation, which affects those industries the most that rely more heavily on transportation. An increase in production costs causes composite prices to increase, which subsequently causes consumer prices to increase. It also causes domestic market share, as well as output, to decrease.

In summary, the higher vehicle price premium operates through several mechanisms in REMI. The price premium associated with regulations has a negative effect on the economy because it causes cars to be more expensive for consumers, resulting in decreased sales of new motor vehicles. Government also experiences increased costs associated with more expensive vehicles and has less revenue available to spend. Private industry's cost of production increases, leading to goods being more expensive to produce, and that makes U.S. producers less competitive, increases imports, and reduces exports.

The impact of higher vehicle prices on total employment, GDP, and real disposable income are presented in Figures 8.3-8.5, respectively. As expected, the employment impacts of the price premium for vehicle consumers—retail consumers, and government and industry fleet purchasers—are negative and increasingly so, until the employment losses reach their peak value around 2025.

The negative employment effects are larger for the 2012 EPA inputs than for the 2012 NHTSA inputs because EPA estimated a higher vehicle price premium than NHTSA. The maximum loss in employment level for the 2012 perspective is over 500,000 jobs in 2025. The modified 2016 perspective has a larger vehicle price premium

Figure 8.3. Difference in Employment Between Baseline and Price Premium Scenarios.

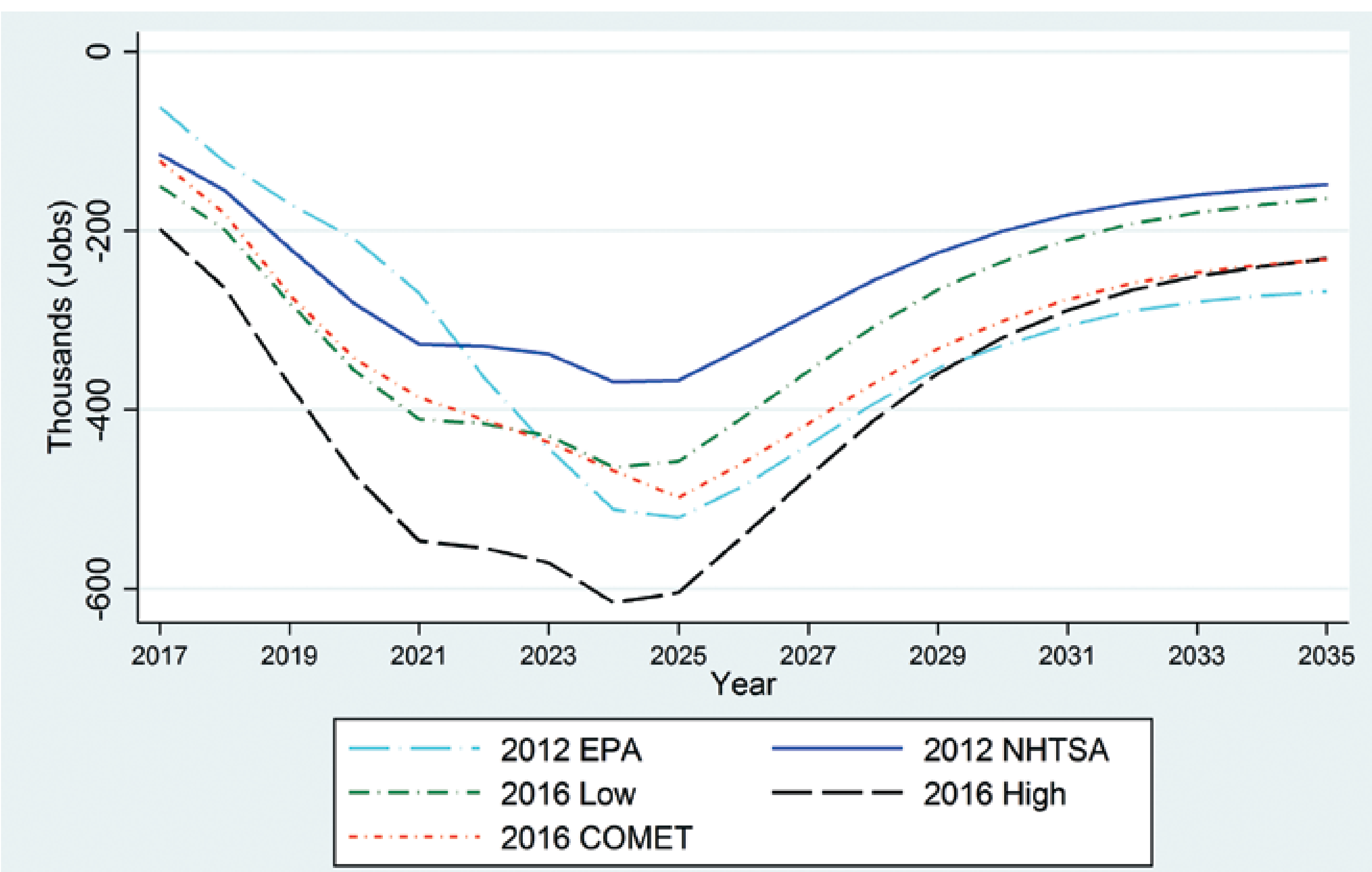
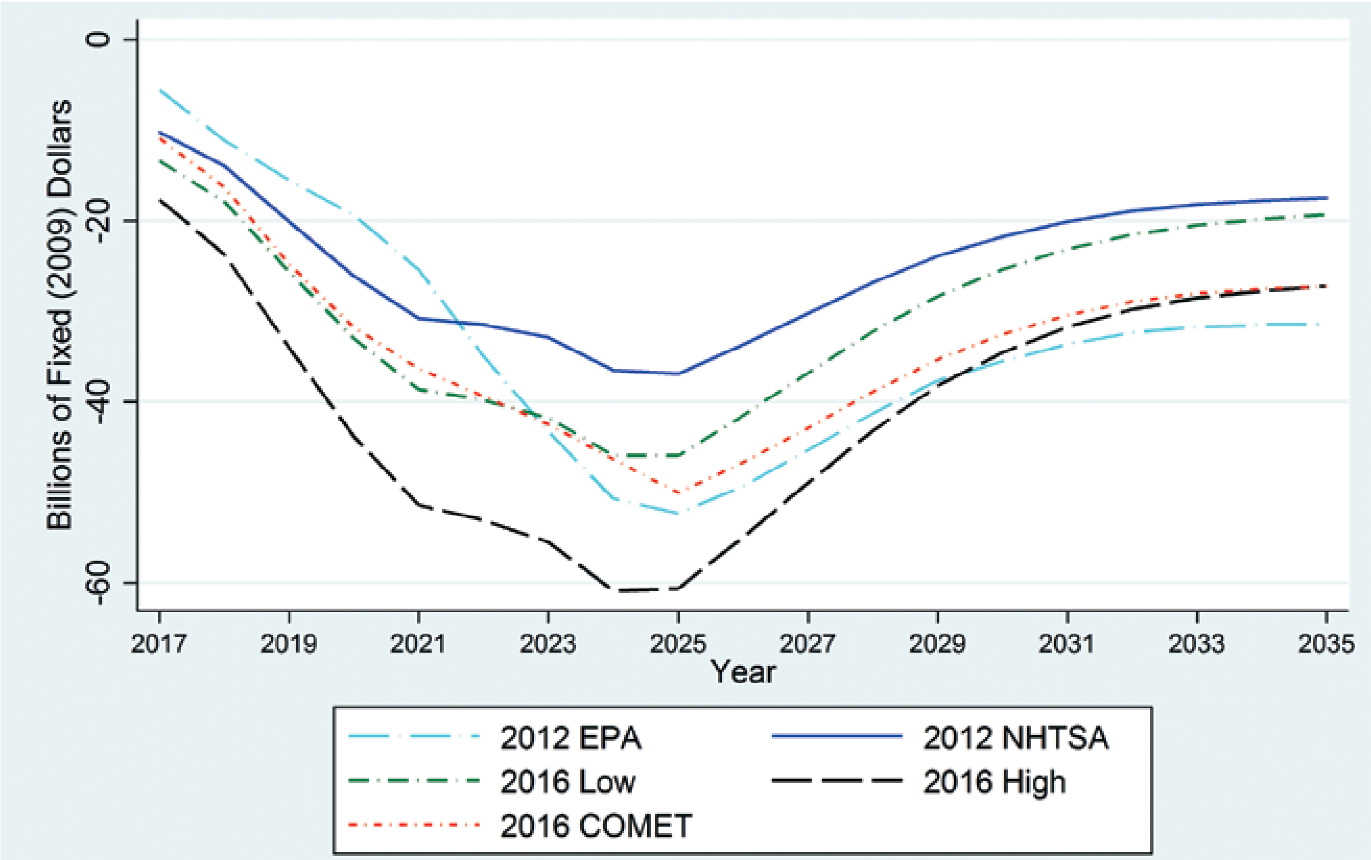
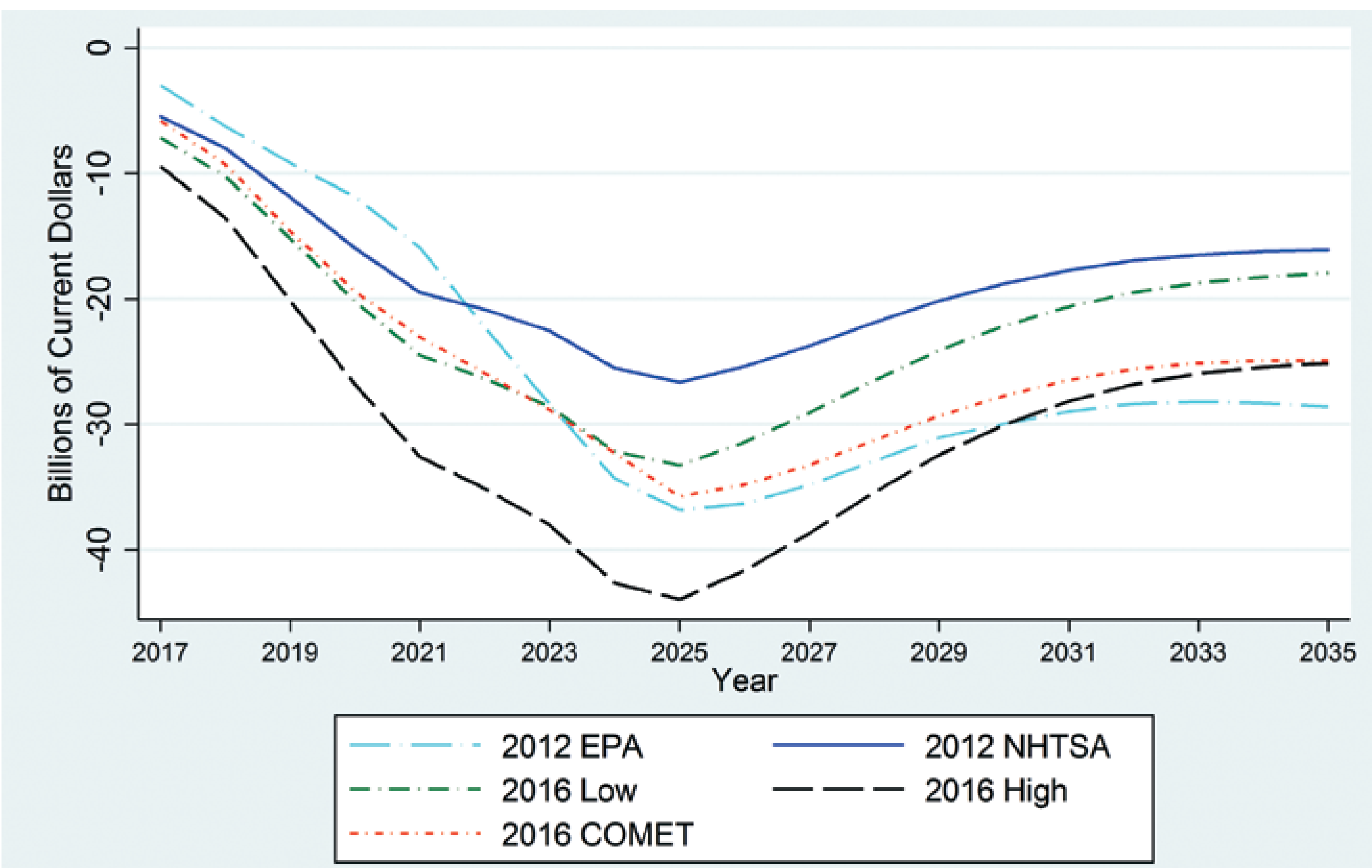


Figure 8.4. Difference in GDP Between Baseline and Price Premium Scenarios.



8.5. Difference in Disposable Personal Income Between Baseline and Price Premium Scenarios.



due to the NRC adjustments and ZEV regulation and, as expected, the declines in the level of total employment are larger, with the maximum loss estimated at over 600,000.

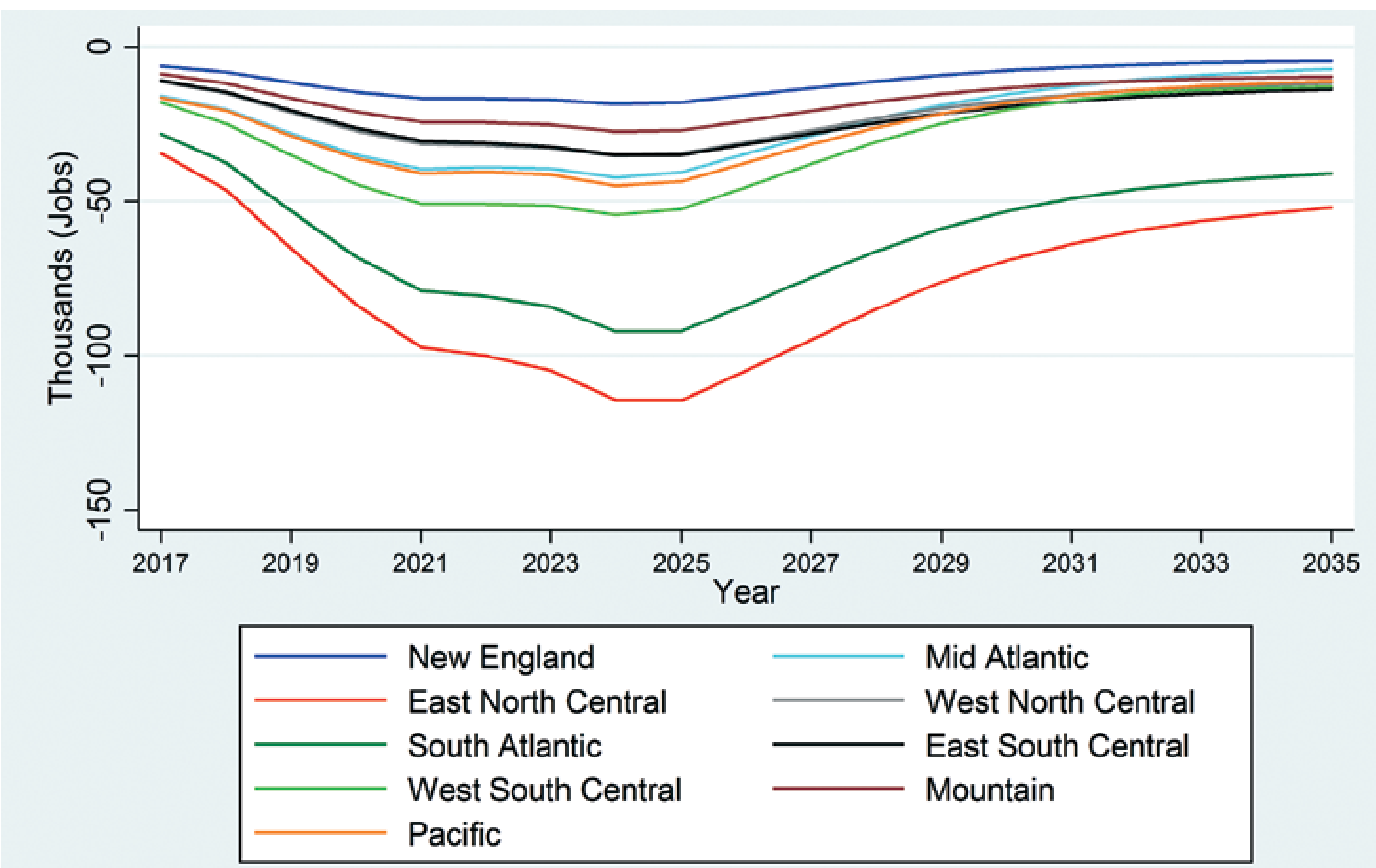
For GDP, the pattern of results is similar. The 2012 perspective shows a loss of $37-$50 billion in GDP around 2025, an effect that is enlarged to a peak of -$60 billion in the modified 2016 perspective. The same pattern of results holds for real disposable income.

Figure 8.6 presents the price premium effect across all nine regions using the 2016 low perspective input data. This graph demonstrates that the price premium mechanism hits the East North Central region the worst, which reveals a loss of over 115,000 jobs in this region around 2025. The South Atlantic region is also negatively affected disproportionately. This finding is consistent with the geographic portrait of the U.S. automotive industry that we presented in section 5. The two regions that are least negatively affected by the price premium are New England and the Mountain region.

Results for GDP and personal disposable income demonstrate similar trends across the regions, thus we do not present them here (but can be made available upon request). Results vary in magnitude for the other 2016 perspective input datasets but not in general trends.

Note that adverse effects of the regulation through higher vehicle prices dissipate from 2026-2035 for two independent reasons: we have assumed that the price premiums decline gradually each year after 2025, as the industry finds more cost-effective ways to comply with the regulations. REMI is built to represent an economy that responds and recovers to external shocks such as an exogenous increase in vehicle prices due to regulation. Our results do not account for the possibility that regulators could tighten or relax the regulations from 2026-2035.

Figure 8.6. Difference in Employment Between Baseline and Price Premium Scenarios Using the 2016 Low Perspective Dataset, by Region.



8.52 The Automobile Supply Chain Reinvestment (Innovation) Effects

The stimulus to the supply chain from the vehicle price increase is expected to boost the economy. Specifically, the increase in sales for R&D, labor, and parts is equivalent to an increase in output, which should cause the optimal level of capital to increase, and thus investment, and results in a feedback effect that increases output further. An increase in employment has a similar effect in REMI. More employment causes the optimal capital stock to increase, which raises investment. Higher investment causes output to increase, which again feeds back to employment.

The isolated effects from this innovation investment, in the absence of the negative price premium effect on consumers, total employment, GDP, and real disposable income are presented in Figures 8.7-8.9. In other words, we imagine a hypothetical scenario where the supply chain is boosted without experiencing any adverse effects of the vehicle price increase.

By 2025, GDP is $25-32 billion above baseline in the 2012 perspective and $30-40 billion above baseline (due to the higher price premium) in the 2016 perspective. Real disposal income in 2025 is up $19-26 billion in the 2012 perspective and $24-33 billion in the modified 2016 perspective. Employment increases in the 2012 perspective range from about 215,000 to 300,000 jobs in 2025. Employment increases in the 2016 perspective range from about 280,000 to 390,000 jobs, the majority of which occur in the South Atlantic and East North Central regions (see Figure 8.10).

Comparing the aggregated innovation effects to the vehicle price effects, as presented in the previous section, reveals that the positive effects from innovation are at least half the size of the losses from the vehicle price effect. For the employment indicator, the losses from the vehicle price effect ranged from 380,000 to 600,000 (2025)

Figure 8.7. Difference in Employment Between Baseline and Automobile Supply Chain Innovation Scenarios.

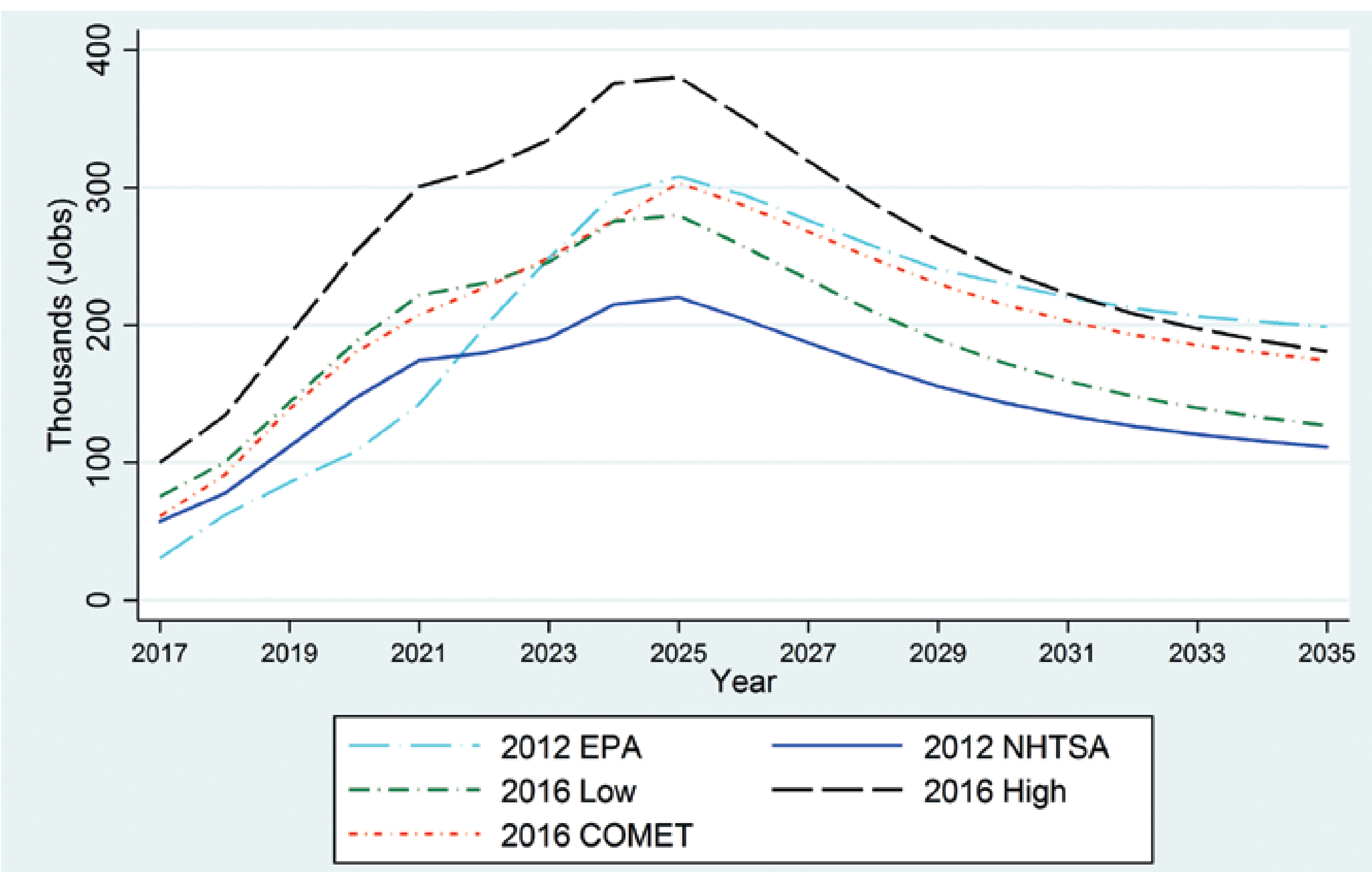


Figure 8.8. Difference in GDP Between Baseline and Automobile Supply Chain Innovation Scenarios.

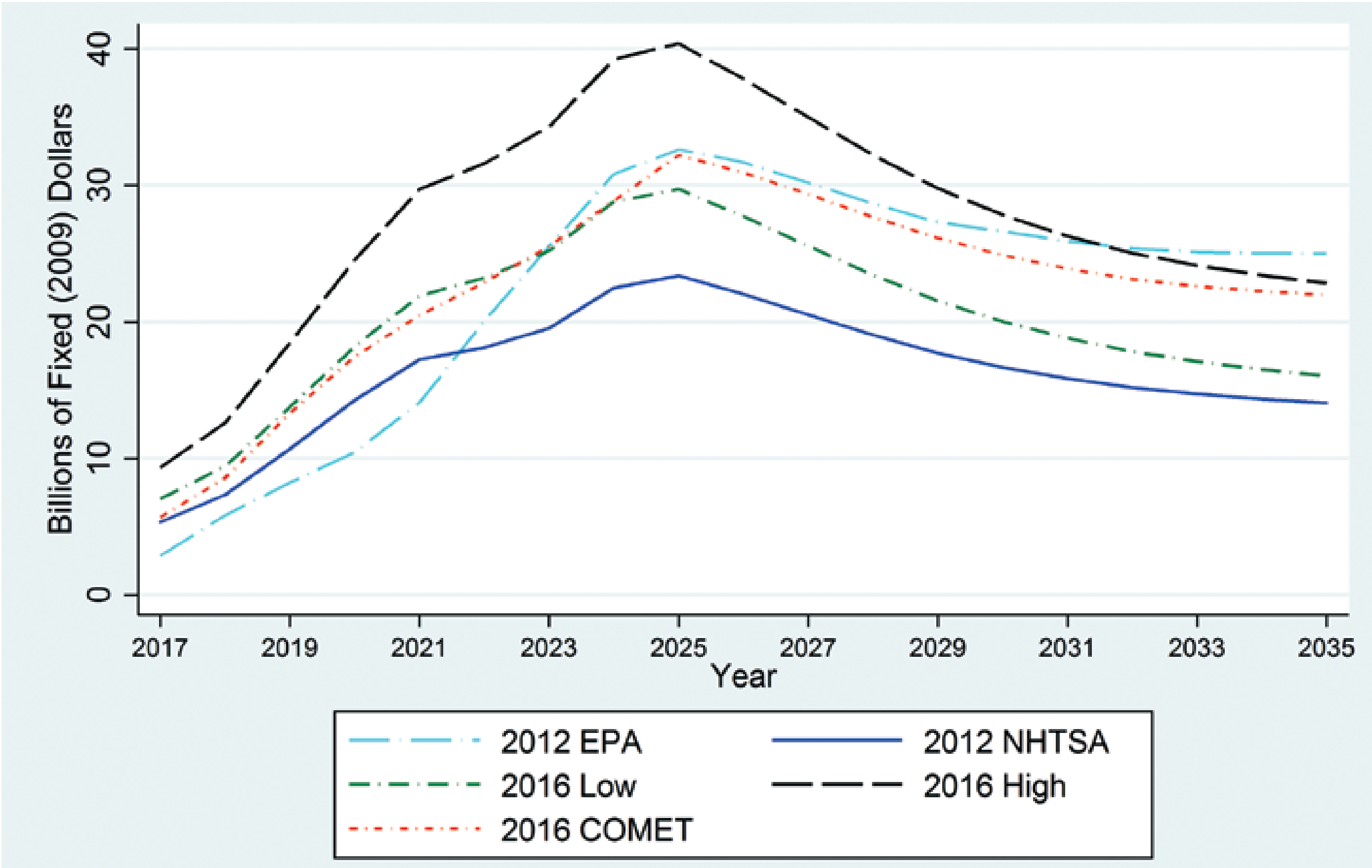


Figure 8.9. Title: Difference in Disposable Personal Income Between Baseline and Automobile Supply Chain Innovation Scenarios.

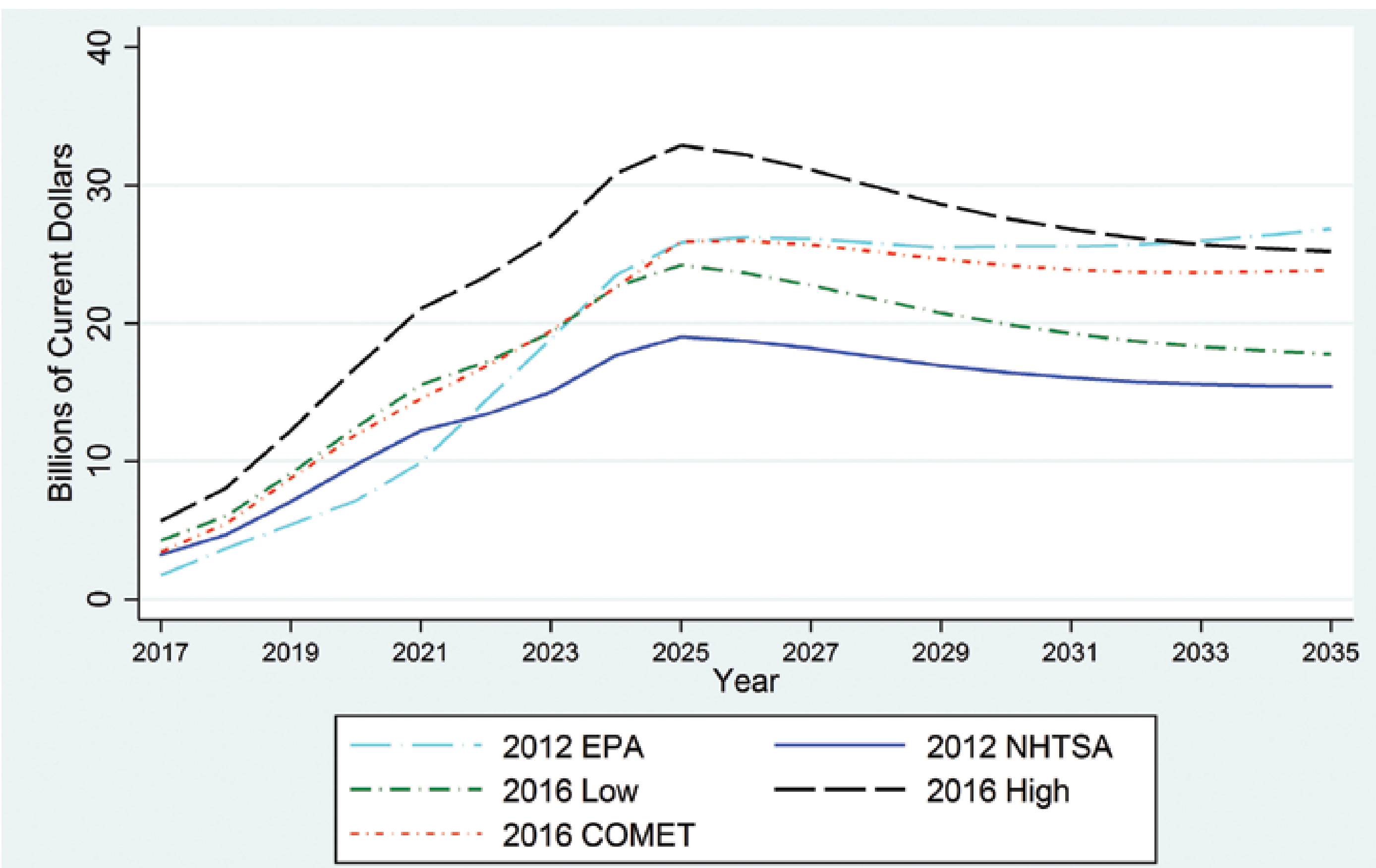
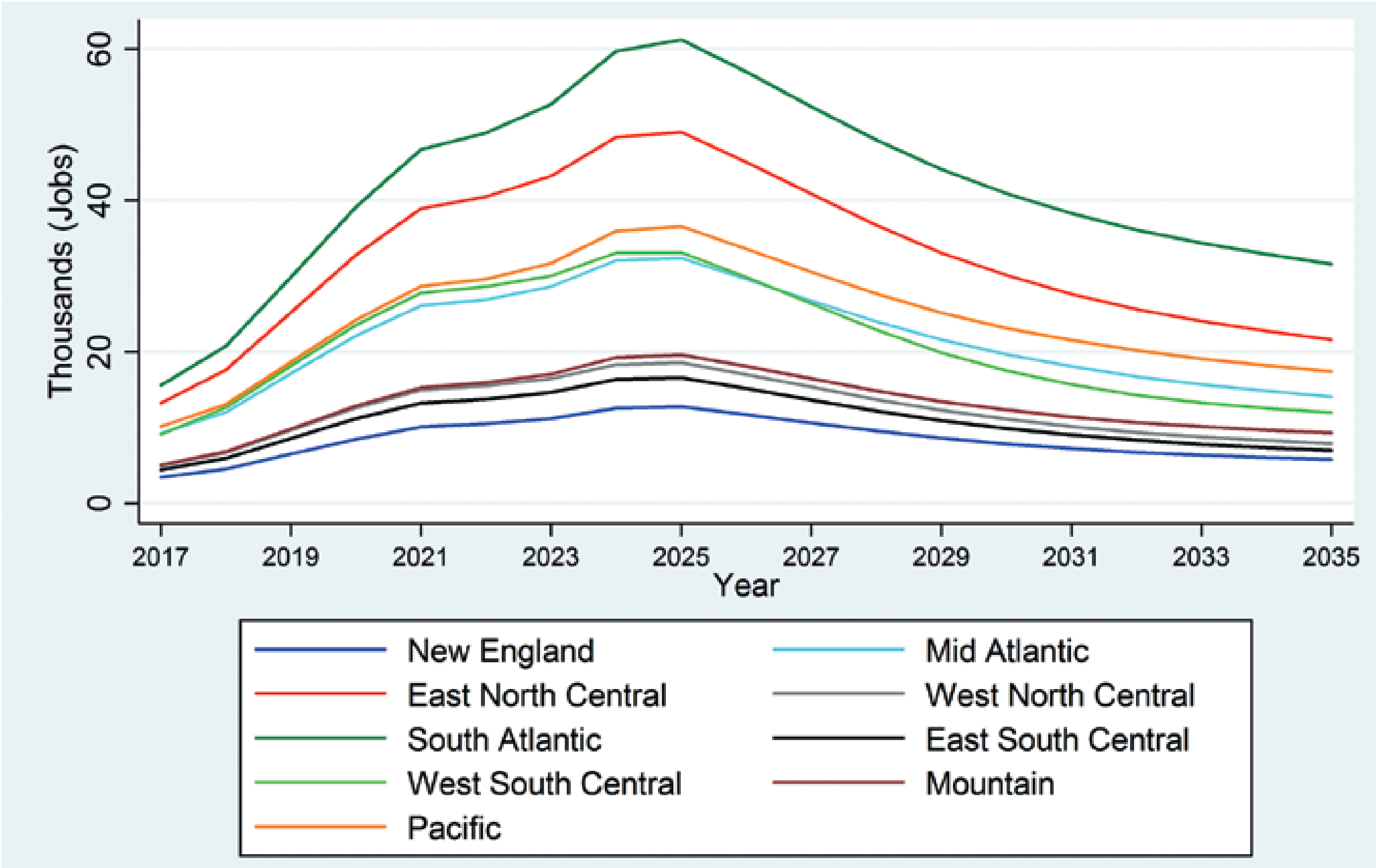


Figure 8.10. Difference in Employment Between Baseline and Automobile Supply Chain Innovation Scenarios Using the 2016 Low Perspective Dataset, by Region.



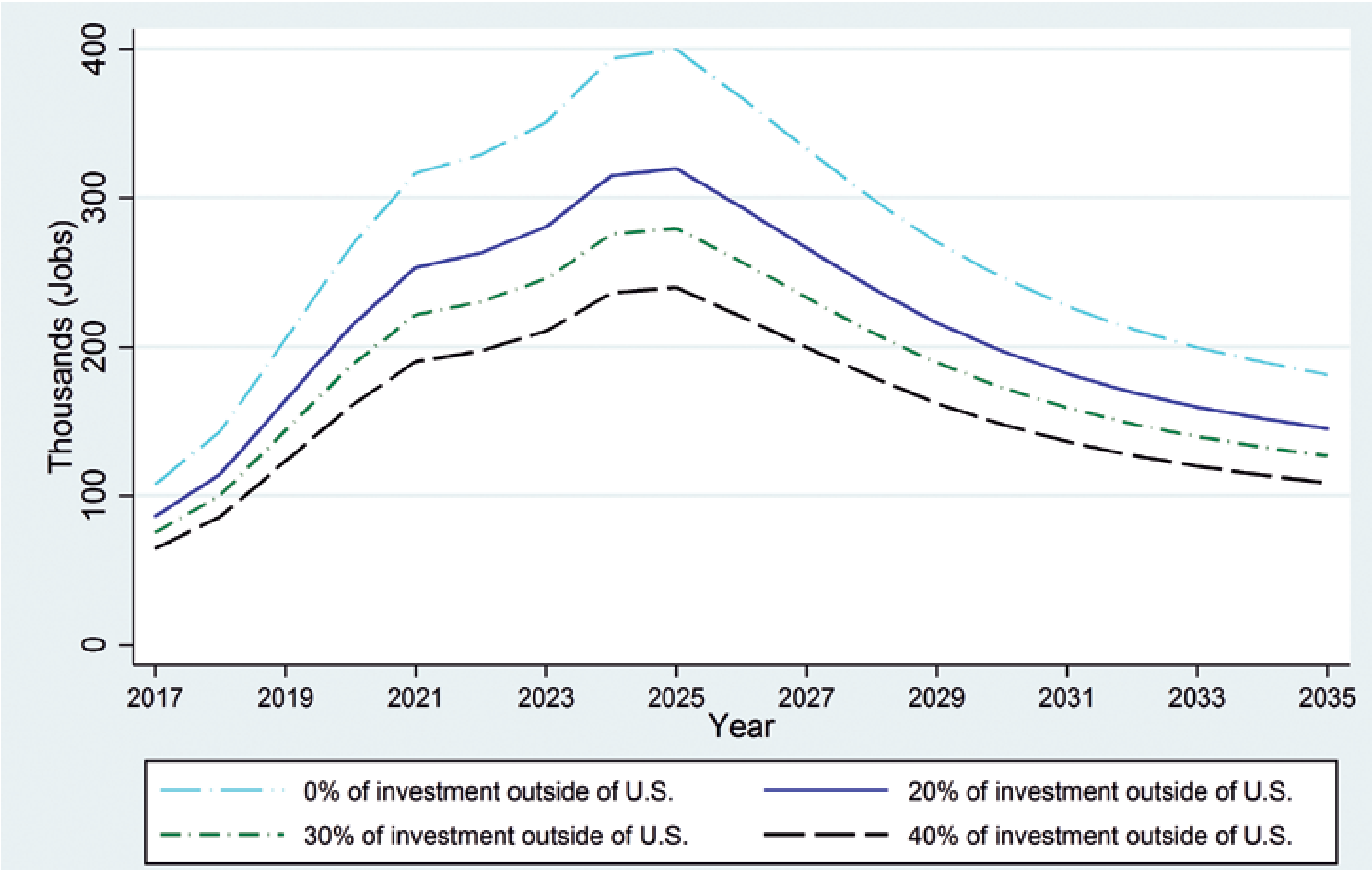
whereas the gains from the innovation effect ranged from 200,000 to almost 400,000 (2025). Note the gains from the innovation effect relate not just to the development of fuel-saving technologies but also to their application (deployment) to large volumes of new vehicles. The attenuation of the gains from 2026-2035 occurs for the same reasons that were explained earlier on the vehicle price effect (i.e., gradually declining price premium and economy-wide adjustments).

We also ran a sensitivity analysis on the assumption that 30% of all supply chain innovation investments are made outside of the U.S. Figure 8.11 displays employment estimates due to the supply chain innovation in which the assumption about percentage allocation outside the U.S. economy varies from 0% to 40%. As this graph demonstrates, the percentage selected matters. If we assume that 0% of all the innovation investments within the auto industry triggered by U.S. regulations happens in other countries (i.e., 100% of the supply chain reinvestment occurs within the U.S.), then the U.S. could experience as many as 400,000 new jobs in 2025. Of course, this estimate is unrealistic, as some of the marginal revenue from the U.S. price increase is used to finance new investments in emerging markets, and some manufacturers are more likely than others to reinvest in North America. Even those manufacturers who reinvest U.S. revenues in North America may allocate some of the investment to Mexico and Canada as opposed to the U.S. Nonetheless, the 0% analysis provides insight as a bounding calculation. If we instead assume that 40% of all innovation occurs on foreign soil, then the employment benefit from these regulations would be closer to 240,000 jobs in 2025.

8.53 The Fuel Savings Stimulus

Both consumption reallocation and consumer spending increase consumption, which positively affects output, employment, optimal capital stock, and investment. Industry production cost reductions make U.S. industry

Figure 8.11. Sensitivity Analysis on the Difference in Employment Between Baseline and Automobile Supply Chain Innovation Scenarios.



more competitive, which has favorable trade ramifications such as more exports and less vulnerability to import competition.

A losing sector in this process is oil, since the decline in demand for gasoline reduces the U.S. demand for oil, which in turn reduces oil imports and reduces the demand for U.S. oil extraction. These conditions affect not only oil extraction but also the supply chain for oil production (e.g., oil refining, transport and refueling stations, equipment for exploration and drilling, and materials used in oil and gas development).

The macro impacts of the fuel savings are large but, as expected, it takes time for them to accumulate due to the long lifetimes of vehicles. The effects on total employment, GDP, and real disposable income are presented in Figures 8.12-8.14. Under the 2012 perspective, the gains in employment reach about 225,000 to 325,000 in 2025 and continue to climb to between 550,000 and 700,000 million in 2035 (notice the y-axes are more compressed than was the case for the vehicle price and supply-chain effects). These gains are attenuated in the modified 2016 perspective. They rise to about 160,000-200,000 in 2025 and 190,000-380,000 in 2035.

As Figure 8.15 reveals, the South Atlantic region benefits the most from the gas savings effect while the oil-producing West South Central region is negatively affected across the entire study period. The pattern of results for GDP and real disposable income are similar to the employment effects.

Across all three macroeconomic indicators, the results for the COMET 2016 Perspective, while favorable to the economy due to fuel savings, are not as large as found with the other data sets. The difference in results between the COMET and the other 2016 perspectives is due to the significantly lower estimates of national fuel savings derived from the COMET 2016 perspective. The lower fuel savings are, in turn, due to differences in the composition of the new vehicle fleet used in COMET compared to the other datasets. The COMET 2016 perspective is based on

Figure 8.12. Difference in Employment Between Baseline and Gas Savings Scenarios.

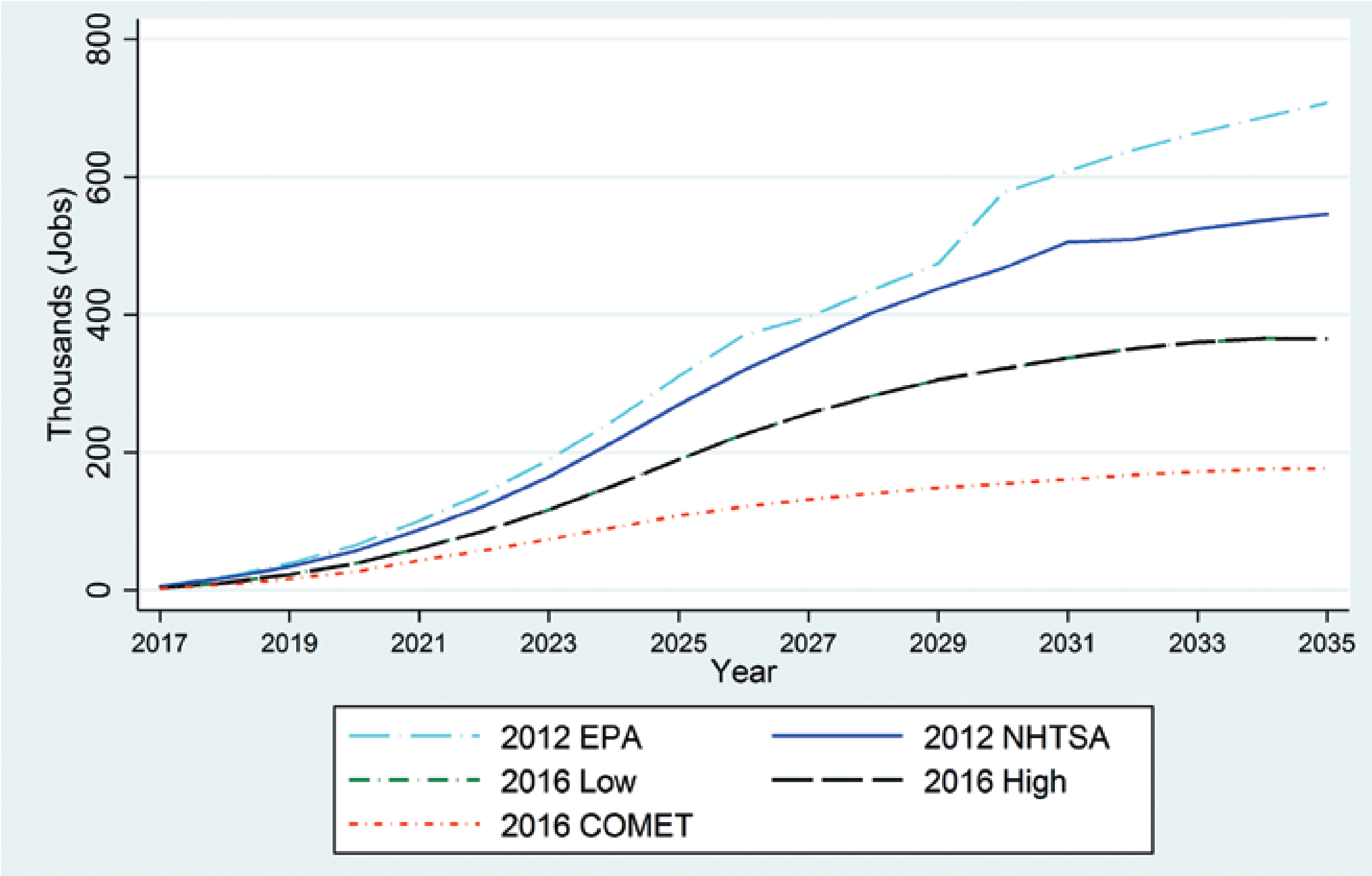


Figure 8.13. Difference in GDP Between Baseline and Gas Savings Scenarios.

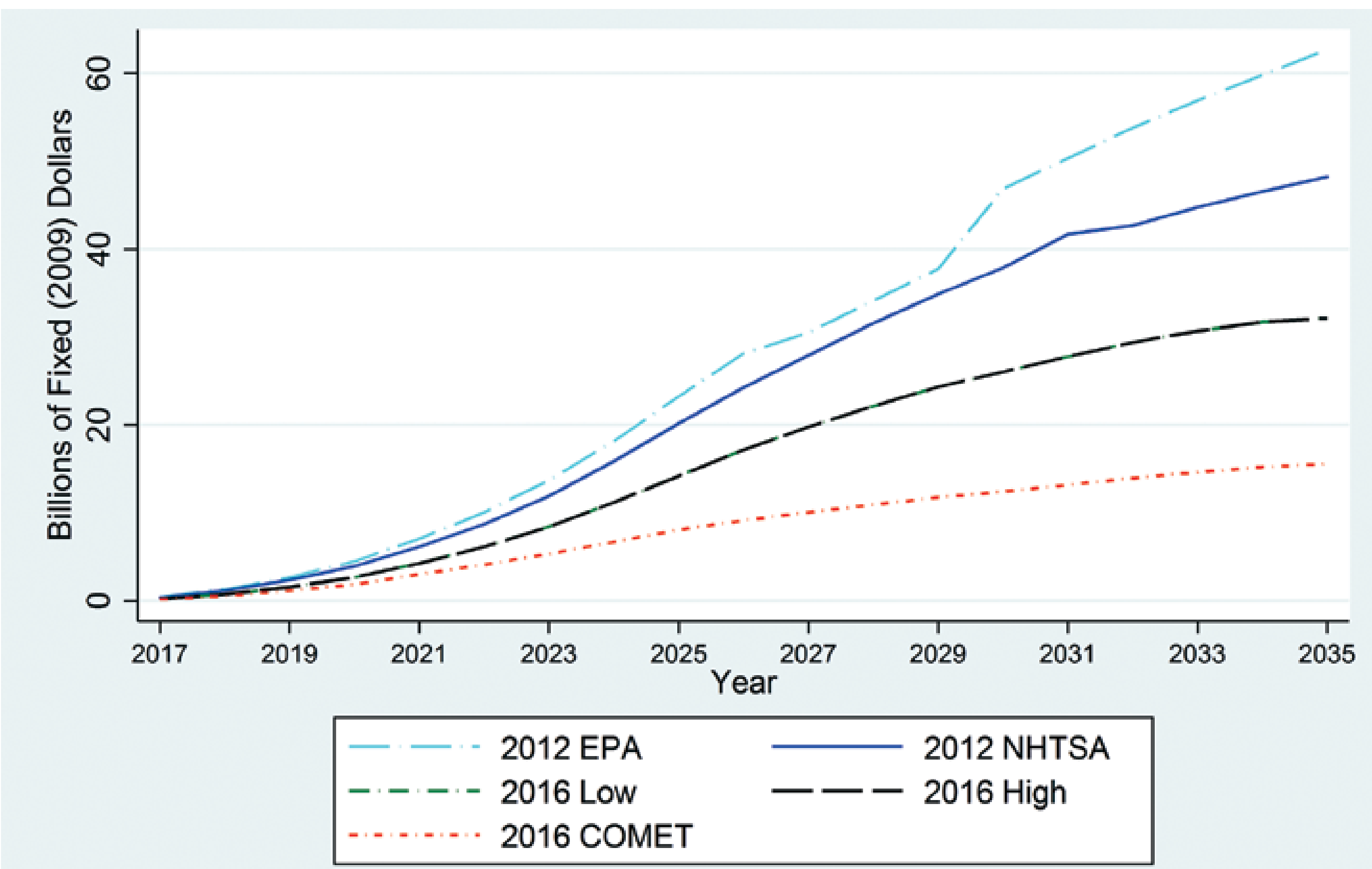


Figure 8.14. Difference in Disposable Personal Income Between Baseline and Gas Savings Scenarios.

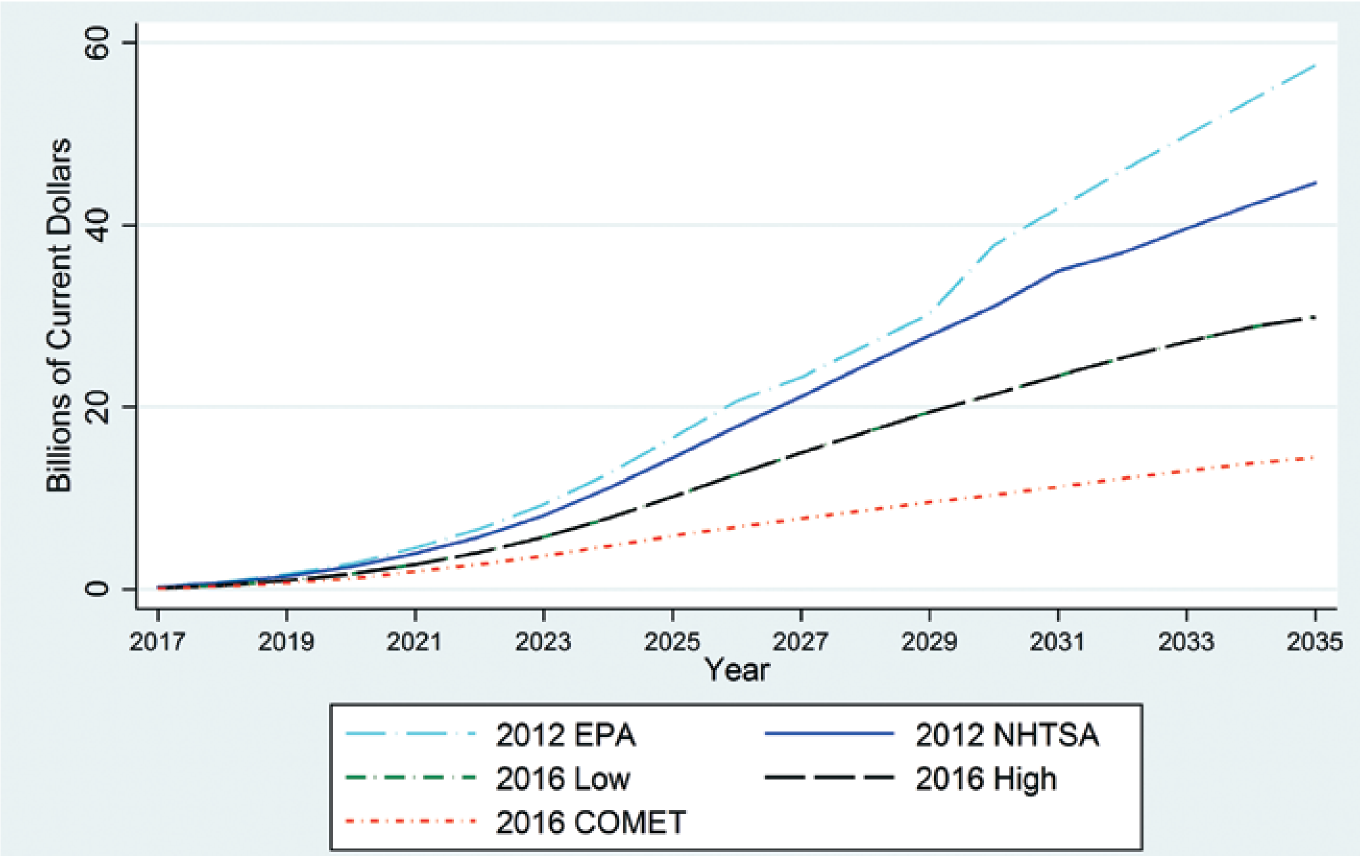
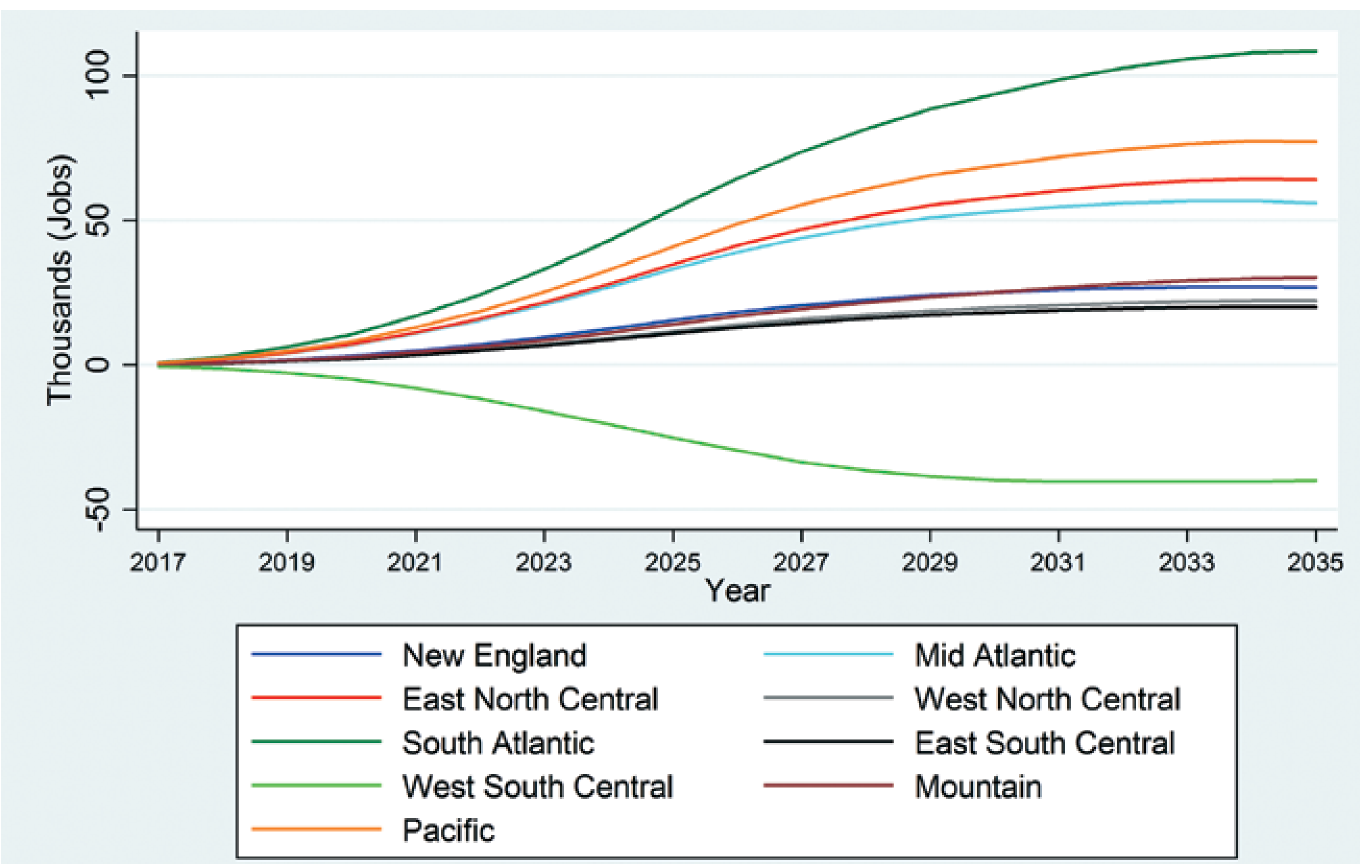


Figure 8.15. Difference in Employment Between Baseline and Gas Savings Scenarios Using the 2016 Low Perspective Dataset, by Region.



an updated version of OMEGA, which assumes that 41% of all vehicles sold between 2017 and 2025 will be cars, while the other 2016 perspectives are based on sales data from the 2012 NHTSA RIA, which reports that 65% of all vehicles sold between 2017 and 2025 will be cars. This shift in the mix of vehicle sales is coupled with another influential factor: the scheduled ramp up in fuel efficiency is much higher (and occurs sooner) for cars than for trucks. Together, those two factors explain the significant difference in fuel savings between COMET and the other perspectives, and hence the difference in fuel savings and macroeconomic impacts.

We explored this difference in fuel savings using a simple simulation on gasoline consumption and found that the total annual gallons of fuel saved between 2017 and 2039 based on the 2012 RIA vehicle data exceed that based on the 2016 TAR vehicle data. In other words, the switchpoint year when the national annual fuel savings from the 2016 COMET perspective become larger than from the other 2016 datasets is 2040. However, the RIA-based (2012) accumulated gallons of fuel saved remains higher than the TAR-based (2016) fuel savings through 2056; the difference is approximately 715 million gallons in 2056, but declining. These observations suggest that the macroeconomic effect of the 2016 COMET perspective should converge toward the fuel savings of the other 2016 perspectives in the years after our data analysis period.

8.54 Combining all Fuel Economy Mechanisms

The combined effects of the vehicle price increases, the supply chain reinvestment innovation effects, and fuel-savings stimulus are presented in Figures 8.16-8.18. We first focus our discussion here on the temporal issue: when do the positive supply-chain and fuel-savings effects outweigh the adverse effects of higher vehicle prices? We then consider cumulative results as well as sensitivity analyses.

For total employment, under the 2012 perspective, it takes about five years, around 2022, for the annual change in the level of employment to switch from negative to positive. Under the modified 2016 perspective, which is influenced by lower fuel prices and a higher vehicle price premium, the annual net positive effects on employment

Figure 8.16. Difference in Employment Between Baseline and Combined Regulatory Scenarios.

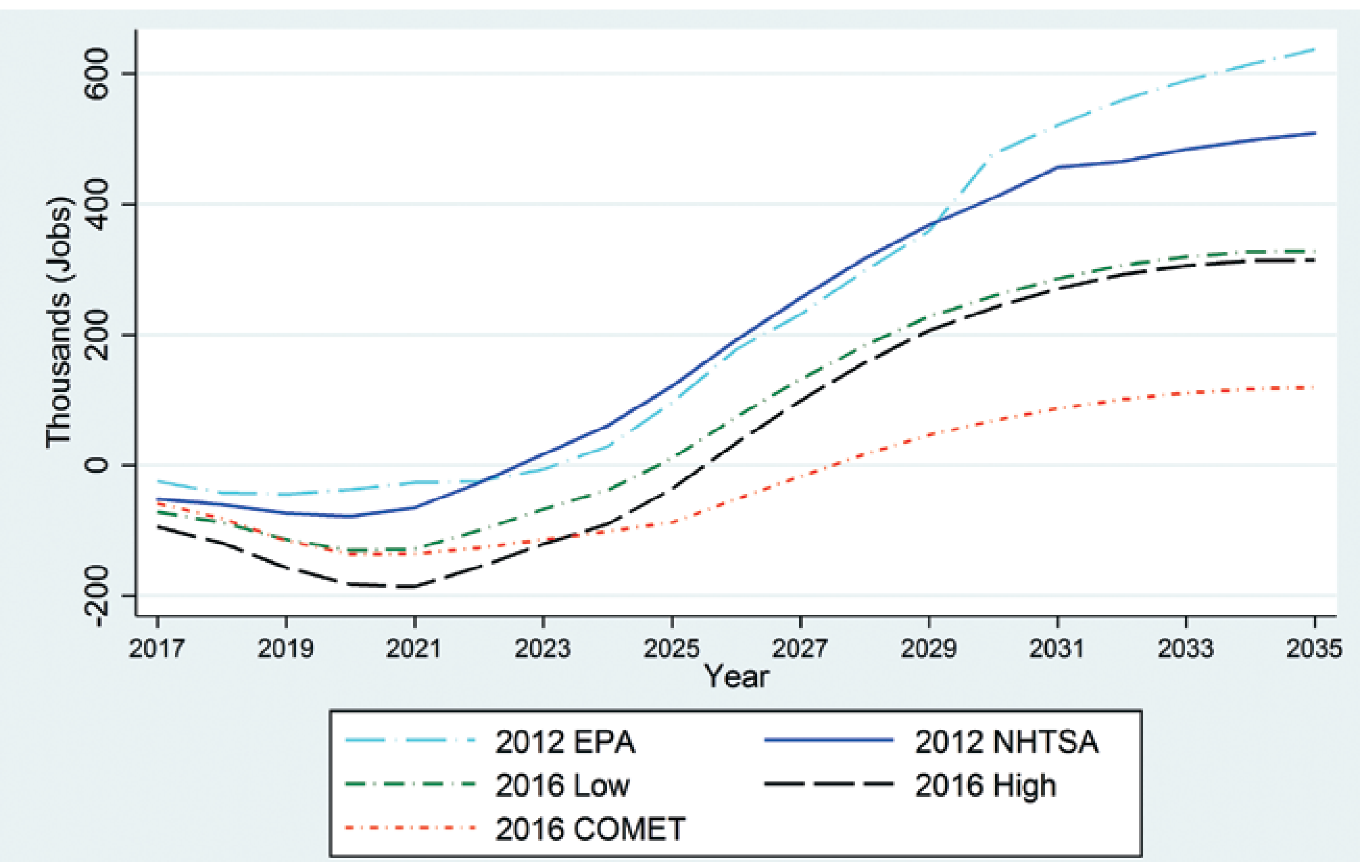


Figure 8.17. Difference in GDP Between Baseline and Combined Regulatory Scenarios.

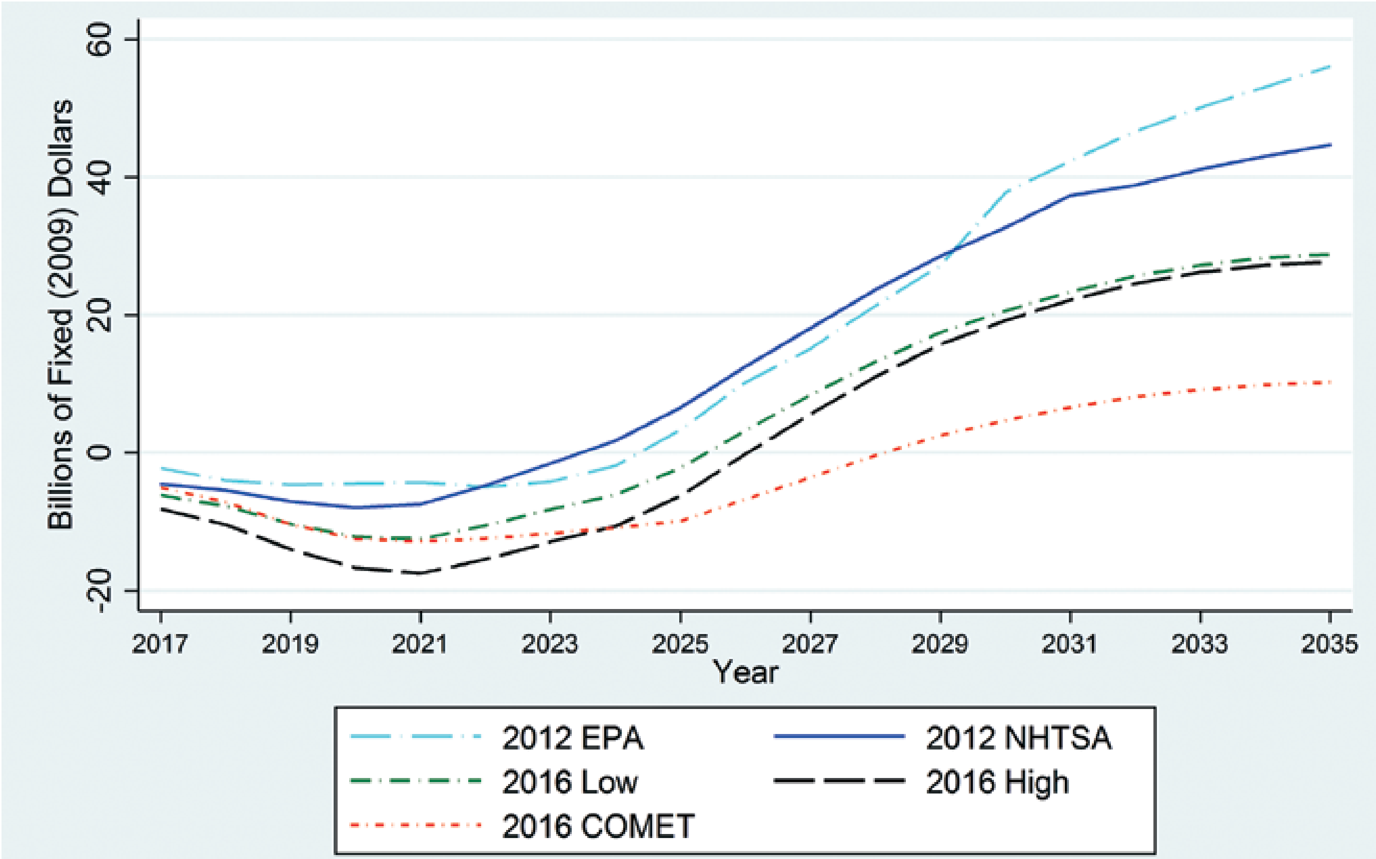
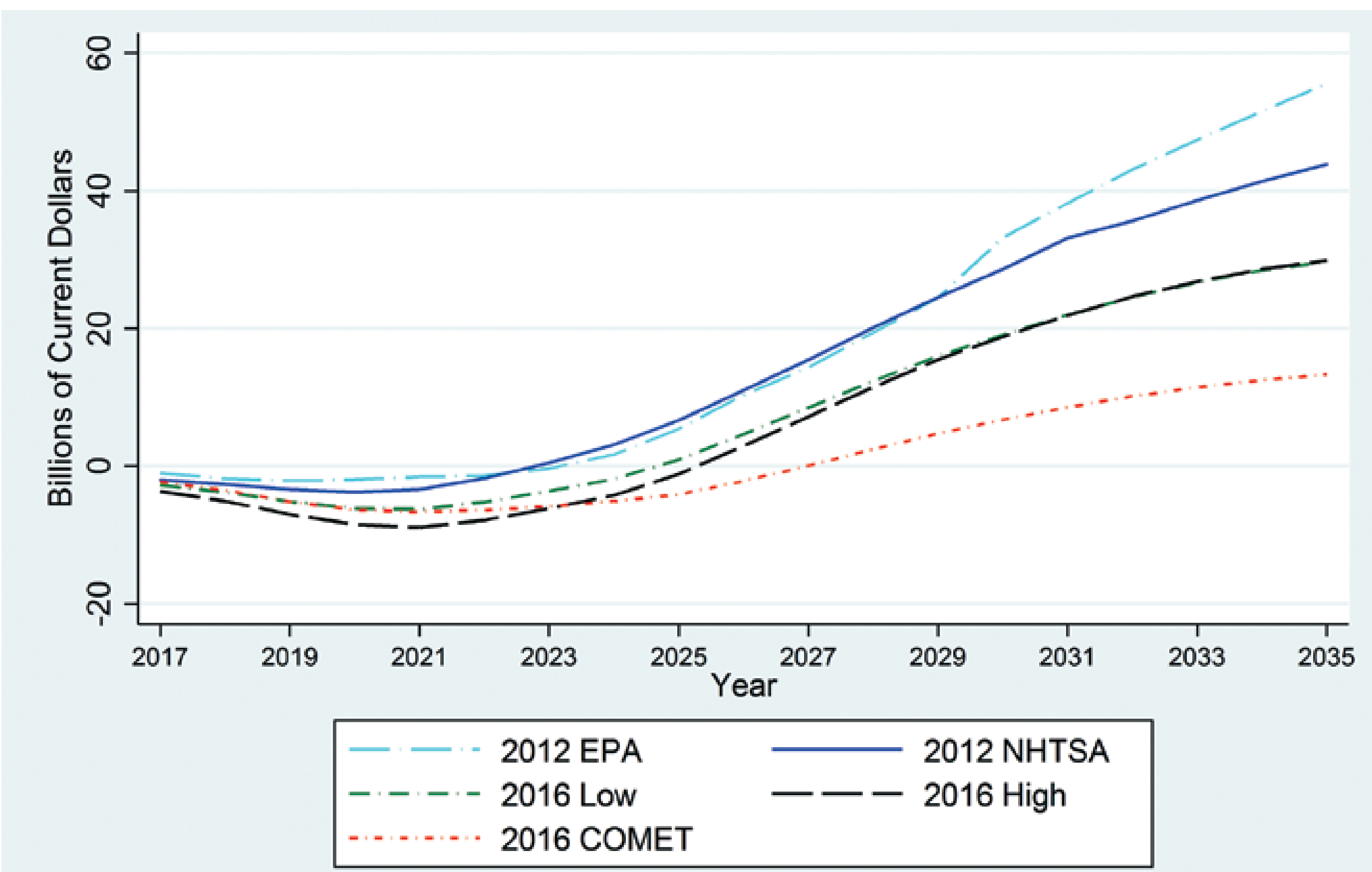


Figure 8.18. Difference in Disposable Personal Income Between Baseline and Combined Regulatory Scenarios.



are delayed until 2024 and 2025 for the low and high 2016 perspectives, and until 2027 for the COMET 2016 perspective. Note that, when employment figures turn positive, they grow steadily and substantially thereafter.

In the case of GDP and personal disposable income, we find similar trends. The 2012 perspective results in positive annual values by 2024, and the annual values for the 2016 perspectives turn positive sometime between 2024 and 2028, depending on the dataset.

Figures 8.19-8.21 show that the annual impacts are not the same across all geographic regions. Here again we present results only for the 2016 low perspective dataset, since the trends are similar across all datasets but with different magnitudes. Three regions appear to benefit the most from the regulations across employment, GDP, and disposable personal income indicators: South Atlantic, Mid Atlantic, and Pacific. The East North Central region starts with the lowest values for all three of these indicators but then recovers faster than other regions, beginning around 2022 and 2023. Unlike all other regions, the West South Central Region never fully recovers from adverse price effects and continues to measure losses through 2035. This region is a large oil producing region, and much of the U.S. supply chain for oil production is also located in this region. Consequently, a decrease in demand for oil hits this region harder than others, even though consumers of gasoline in this region still experience benefits.

8.55 Cumulative Effects

Next we present "cumulative results" where the annual changes in U.S. economic performance are summed over a specified time period. The change in each year is weighted equally in the cumulative assessment. For example, if changes in GDP were -100,000 in year one but +200,000 in year two, the cumulative result for the two year period is +100,000.

Figure 8.19. Difference in Employment between Baseline and Combined Regulatory Scenarios, by Region (2016 Perspective Low).

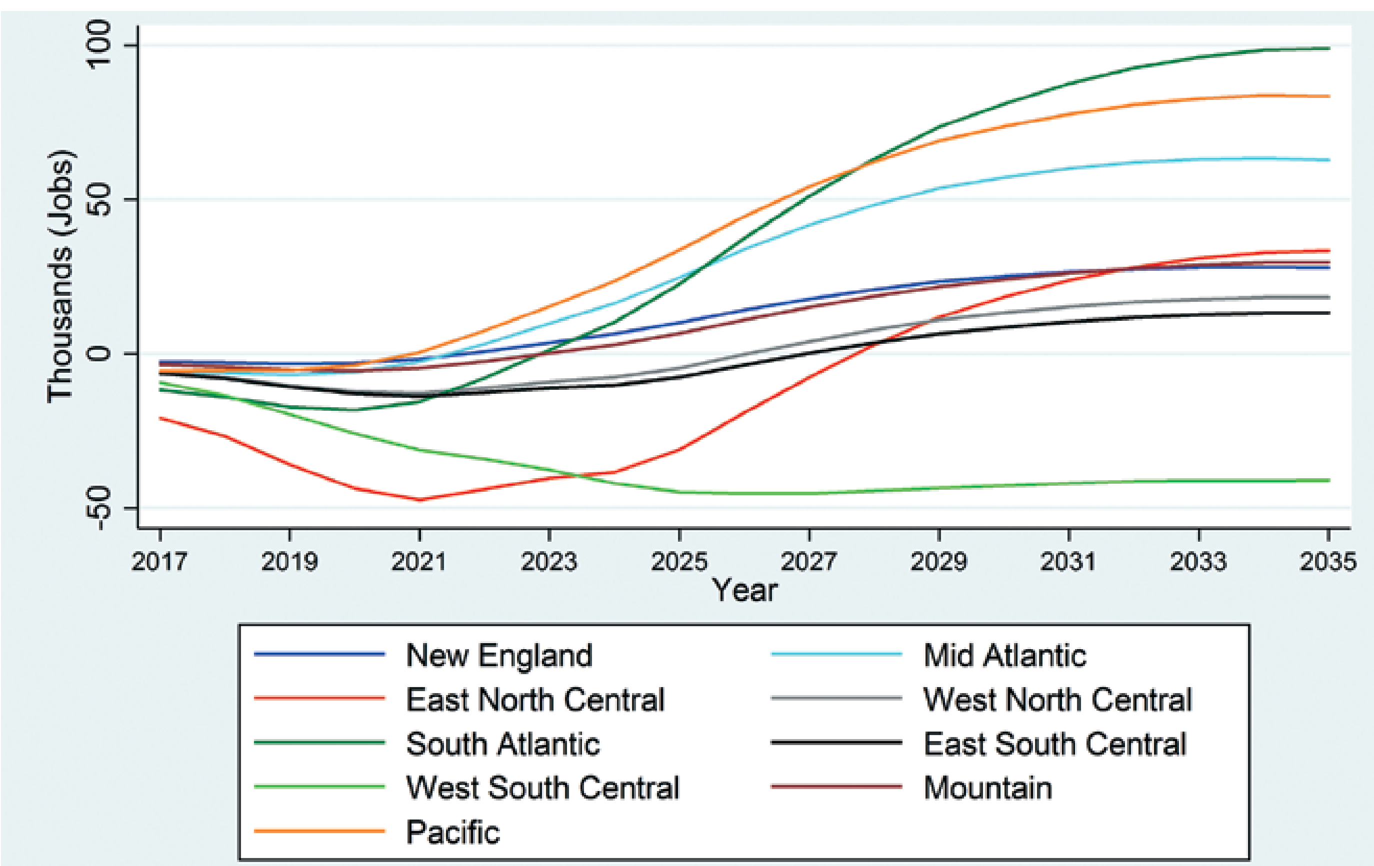


Figure 8.20. Difference in GDP between Baseline and Combined Regulatory Scenarios, by Region (2016 Perspective Low).

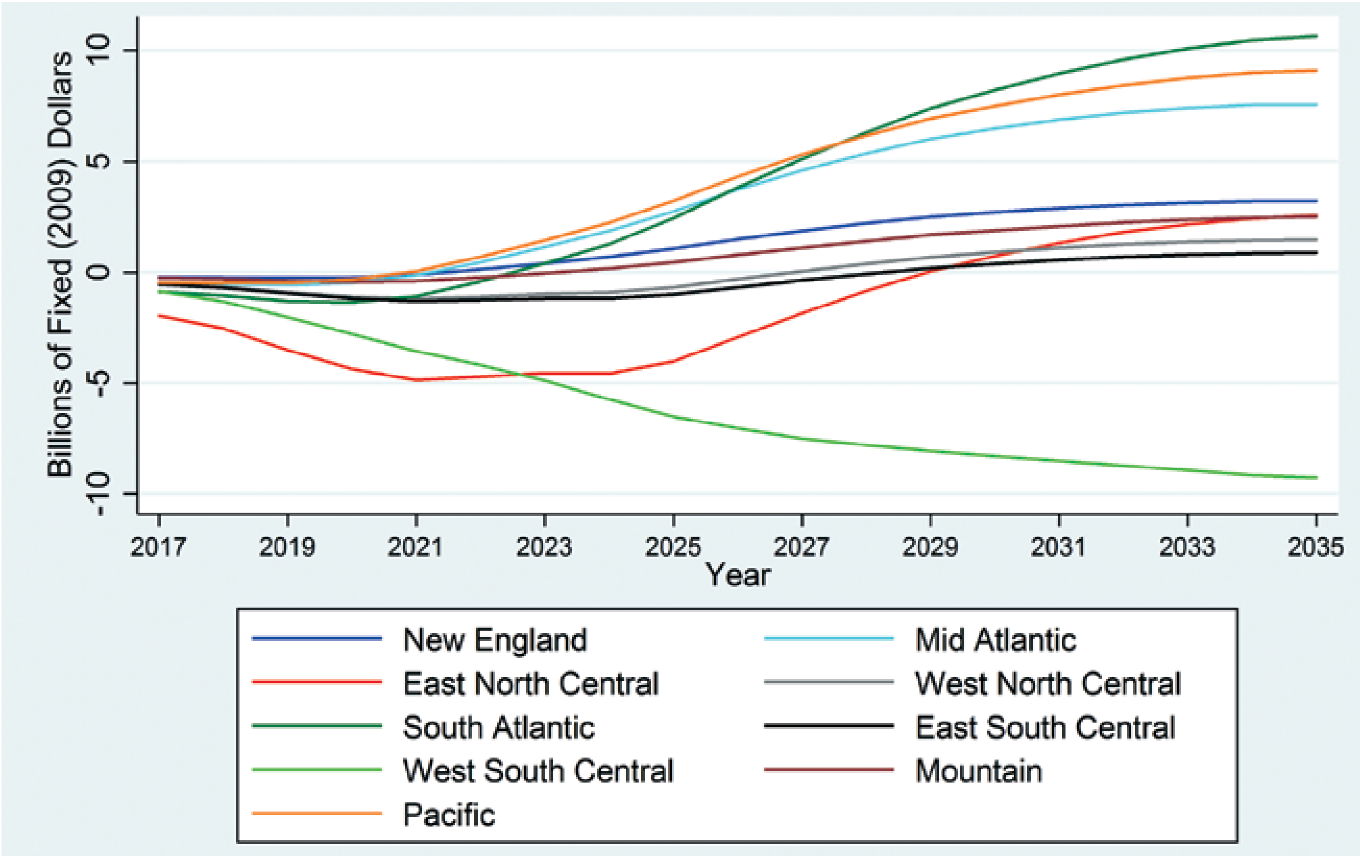


Figure 8.21. TDifference in Disposable Personal Income between Baseline and Combined Regulatory Scenarios, by Region (2016 Perspective Low).

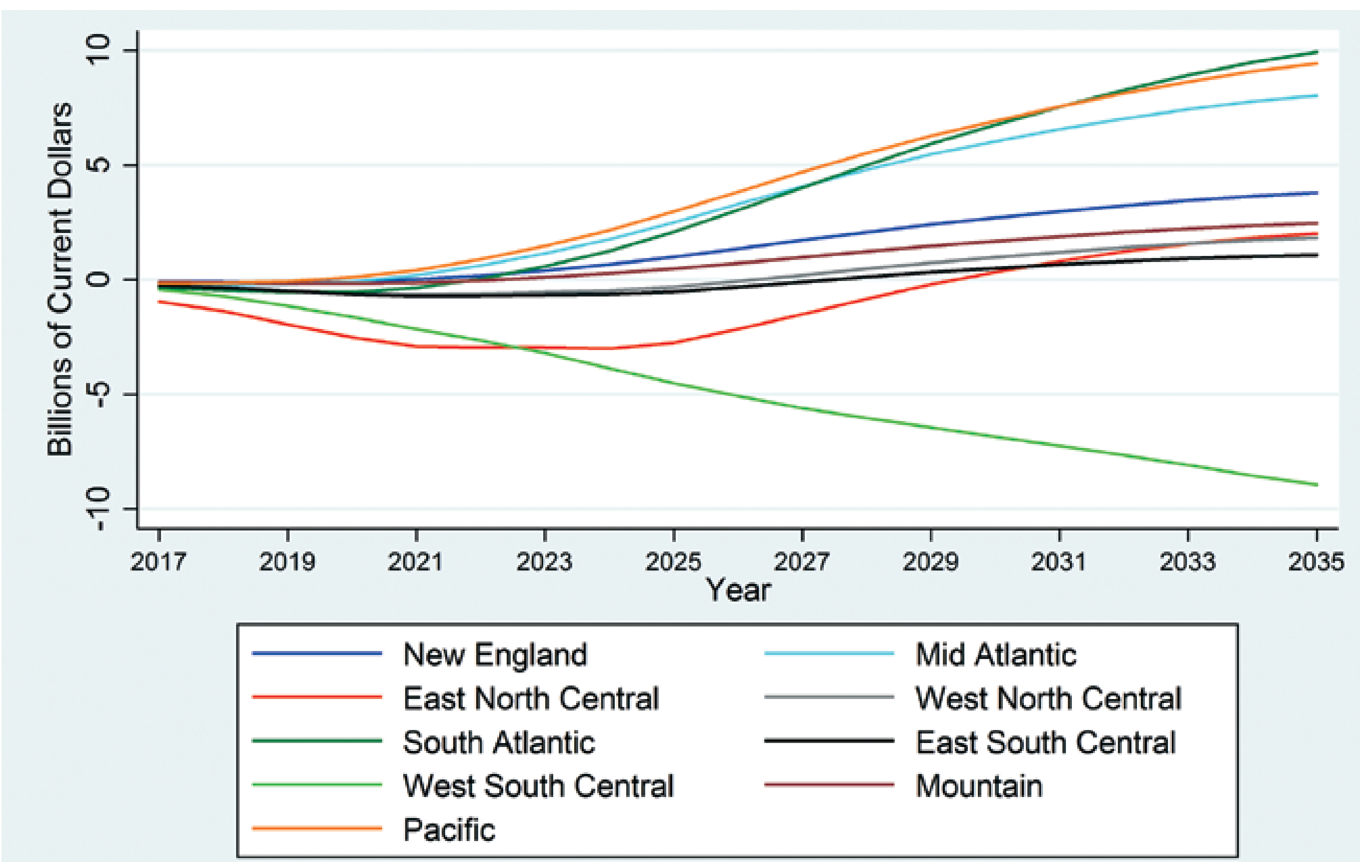


Table 8.1 presents cumulative results across all five datasets and two of the macroeconomic indicators. The first column presents cumulative results between 2017 and 2025, and the second between 2017 and 2035. Employment is not included because the employment estimates are stock variables, and represent job-years; adding these estimates up over time does not result in any meaningful value. The results in this table turn more favorable for two reasons: the gasoline savings continue to accumulate from the fleets of vehicles produced since 2017; and the vehicle price premium stops increasing after 2025, since we have assumed that the regulations remain the same after 2025 (although EPA has begun planning stricter regulations after 2025, according to Beene 2016a).

Table 8.1. Macroeconomic Modeling Results, Cumulative 2017-2025 and 2017-2035

Dataset and Indicator	2017-2025	2017-2035
EPA 2012 Perspective		
GDP	-27.2	332.6
PDI	-2.8	334.6
NHTSA 2012 Perspective		
GDP	-30.3	290.3
PDI	-6.6	285.8
2016 COMET Perspective		
GDP	-92.6	-52.1
PDI	-45.1	22.7
2016 Low Perspective		
GDP	-75.8	120.5
PDI	-33.7	158.2
2016 High Perspective		
GDP	-111.9	67.4
PDI	-52.3	135.5

Note: GDP and PDI in billions of dollars.

The 2016 COMET perspective has net negative impacts on GDP over the longer time period, through 2035. (As we explained earlier, the 2016 COMET perspective will take much longer to produce positive economic impacts because of the assumed high proportion of light trucks). All 2016 perspective datasets result in less favorable estimates of cumulative economic impact than the 2012 perspective datasets.

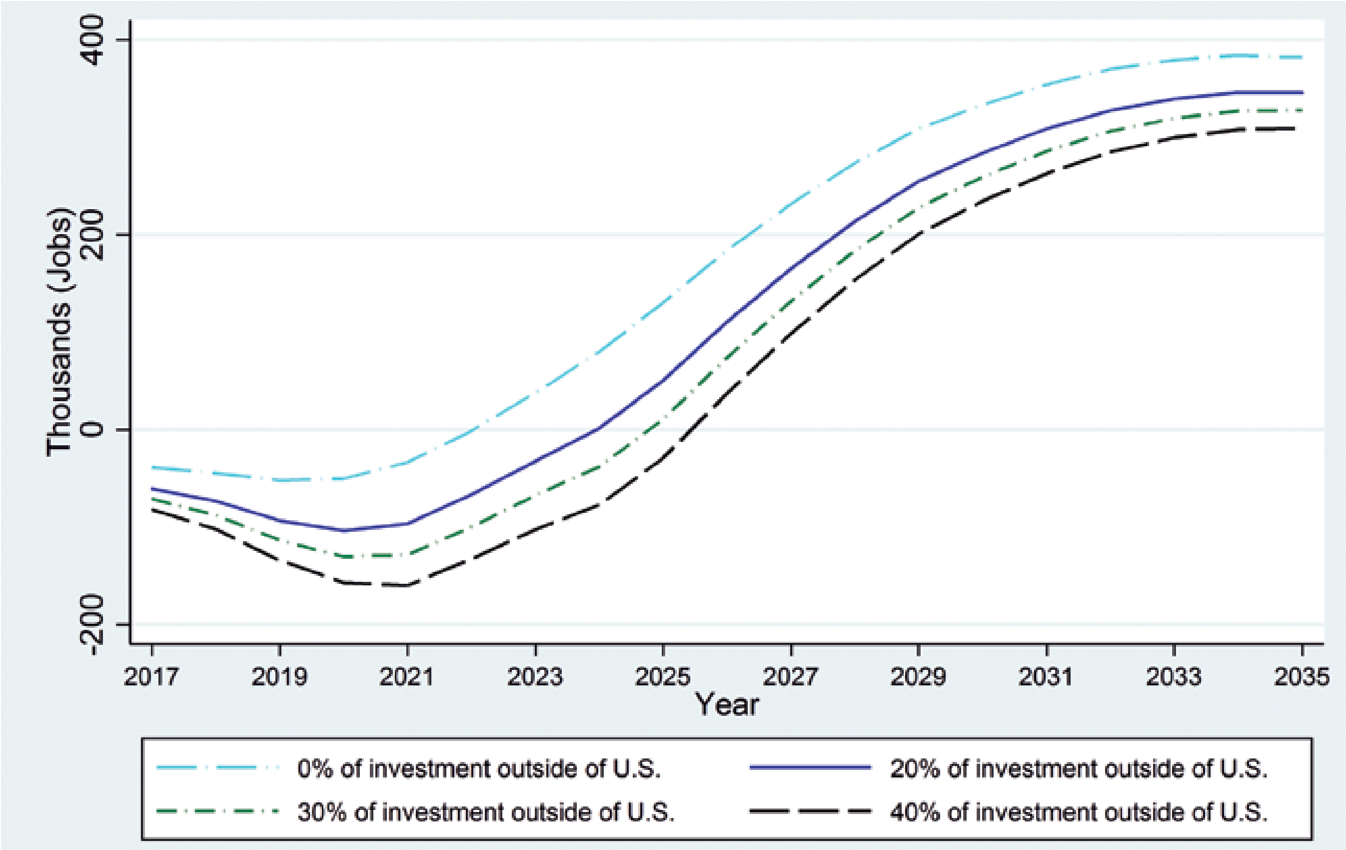
Notice that, although 2025 is the end of the model-year period for the regulatory standards, 2025 is of no particular significance for the purpose of macroeconomic analysis. Indeed, we have shown that the positive fuel-savings effects continue to accumulate for many years beyond 2025. Nor is there anything magic about 2035, though the extra ten years allows the model to capture much of the growing fuel-savings effects. On the other hand, the vehicle price premium stops increasing after model year 2025, and thus it should not be entirely surprising that the gasoline-savings effects gradually overwhelm the vehicle-price and supply-chain innovation effects, which are assumed to take effect from 2017-2025. It is quite possible that more stringent regulations will be enacted after model year 2025, thereby causing additional price premiums, but we have not analyzed those possibilities. More generally, the decades after 2035 introduce many additional uncertainties that are difficult to model. Nonetheless, since the gasoline savings are larger than the vehicle price premiums, the ultimate impacts on the economy will be favorable if the time horizon is lengthened enough.

8.6 Sensitivity Analyses

We also ran two separate sensitivity analyses on the combined results. One addresses the amount of reinvestment in the U.S. automotive supply chain; the other addresses future fuel prices.

In the first, we return to supply chain innovation and the amount of reinvestment that will occur within the U.S. versus elsewhere in the world. In Figure 8.22 we vary this percentage from 0% to 40%, as we did above with the innovation mechanism in isolation. This figure presents only those results for the 2016 low perspective and the employment indicator, since other datasets and indicators are all marked by similar trends. We find again that the model is sensitive to the assumption about the geographic allocation of auto industry reinvestments. When the cumulative results are compared at the extreme input assumptions of 0% and 40% of innovation spending occurring outside the U.S., the break-even point for net gain to the U.S. economy varies by about three years. Whether the three-year difference matters that much is less clear: in either case the regulations under study are a negative for the U.S. economy in the near term, but become a positive for the U.S. economy once a sufficient number of years of gasoline-savings have occurred.

Figure 8.22. Sensitivity Analysis on the Difference in Employment Between Baseline and Combined Fuel Regulatory Scenarios.



Second, we ran sensitivity analyses on gasoline price using the 2016 low and high perspective datasets. In Figures 8.23-8.25, we introduce lower and higher gasoline price projections, as provided by EIA (2016). Results are less positive when the price of a gallon of gasoline is lower, and more positive when the price is higher. The sensitivity adjustments do not result in either scenario switching from negative to positive in more than a half-year to full-year time.

8.7 Limitations, Unresolved Issues, and Future Research

The net economic impacts of the gasoline savings are favorable, large in absolute magnitude, and dominate the long-run results of the REMI modeling. Therefore, besides the sensitivity analyses already presented, it is useful to consider how accurately the model can estimate the effects of fuel savings and how future research can refine our understanding of how gasoline savings affect the U.S. economy. In this section, we consider whether the REMI results are consistent with the impacts of diminished U.S. fuel prices in 2014-16, recent evidence concerning how U.S. consumers are reacting to the savings in fuel expenditures, and how the impacts of gasoline savings on oil imports and U.S. production can be refined in future research.

8.71 Insights from the Recent Collapse of Oil and Gasoline Prices

There is a significant literature in macroeconomics on how abrupt changes in the price of oil and gas have impacted the U.S. and global economies (e.g., see P. Edelstein and Kilian 2009; Hamilton 2011). One of the positive aspects of lower energy prices is a boost to consumer spending on other goods and services. Due to the decline in fuel prices from a peak of roughly $4.00 per gallon (national average in May 2011) to $2.20 per gallon (national average in 2016), the average American motorist has been saving roughly $1,080 per year on gasoline expenses (assuming 15,000 miles per year at 25 miles per gallon) (Blake 2011; Cox 2015; Appelbaum 2016; Soper, Olson, and Townsend 2015; Arora 2015; Skowronski 2015). These savings are of the same order

Figure 8.23. Difference in Employment Between Baseline and Combined Regulatory Scenarios with Low and High Gasoline Prices.

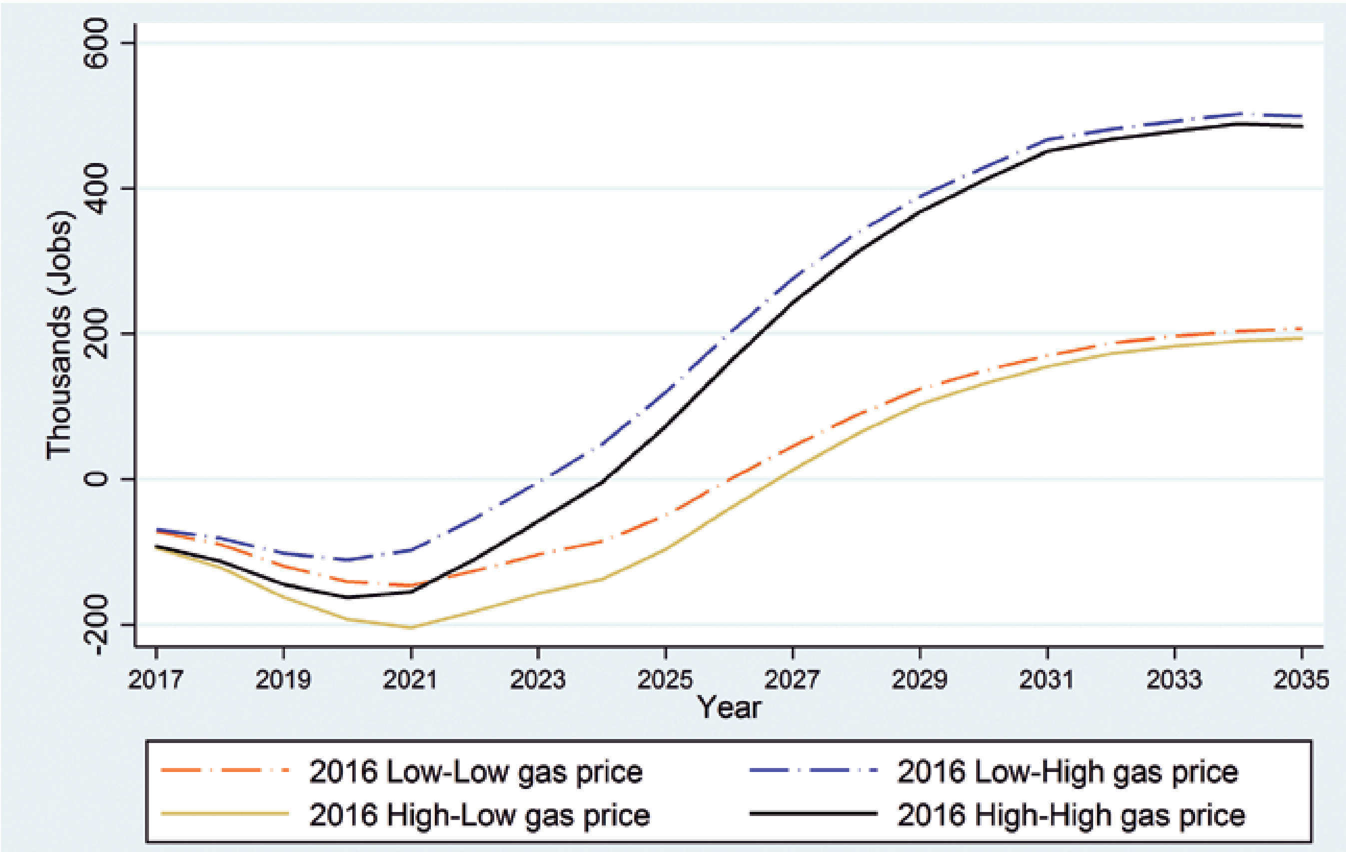


Figure 8.24. Difference in GDP Between Baseline and Combined Regulatory Scenarios with Low and High Gasoline Prices.

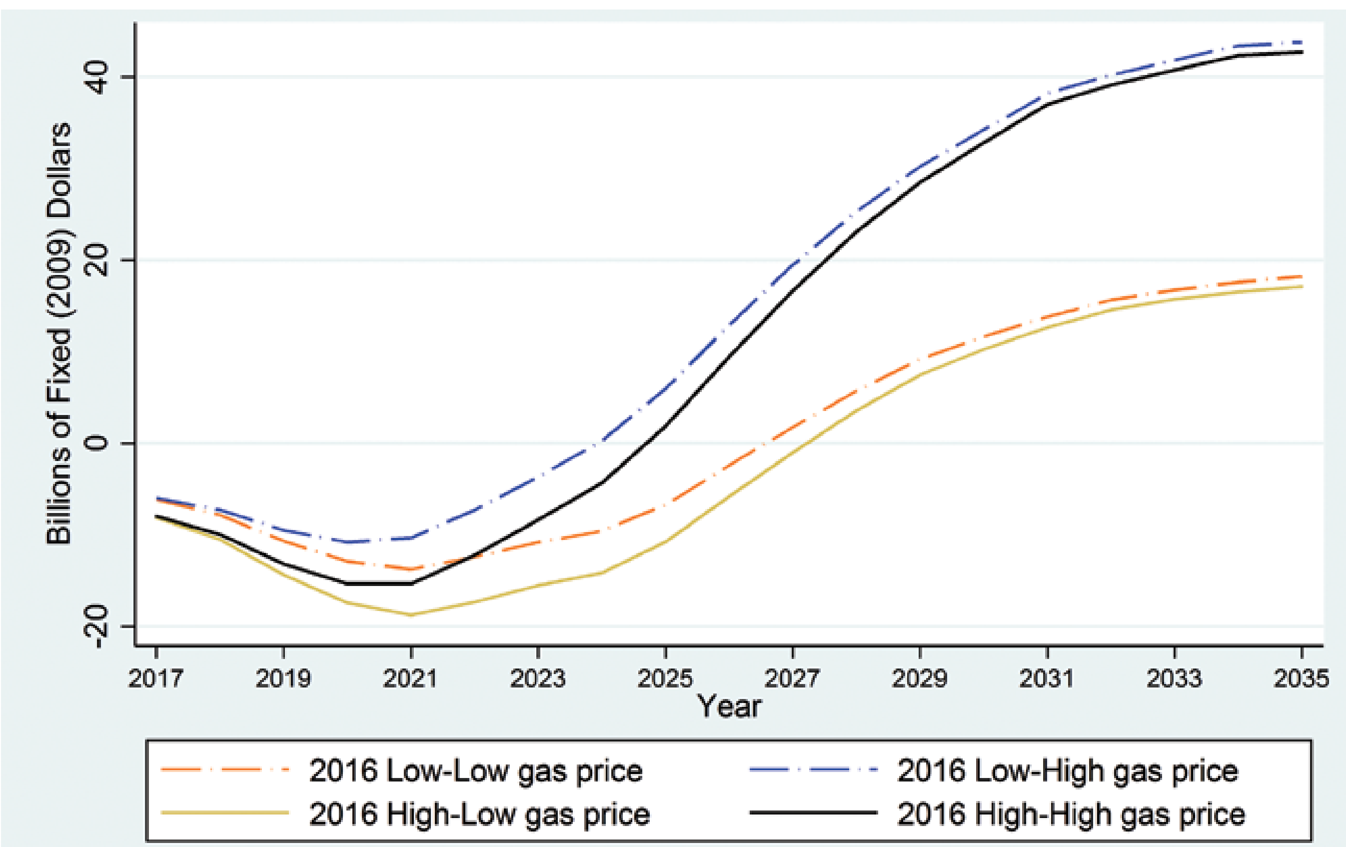
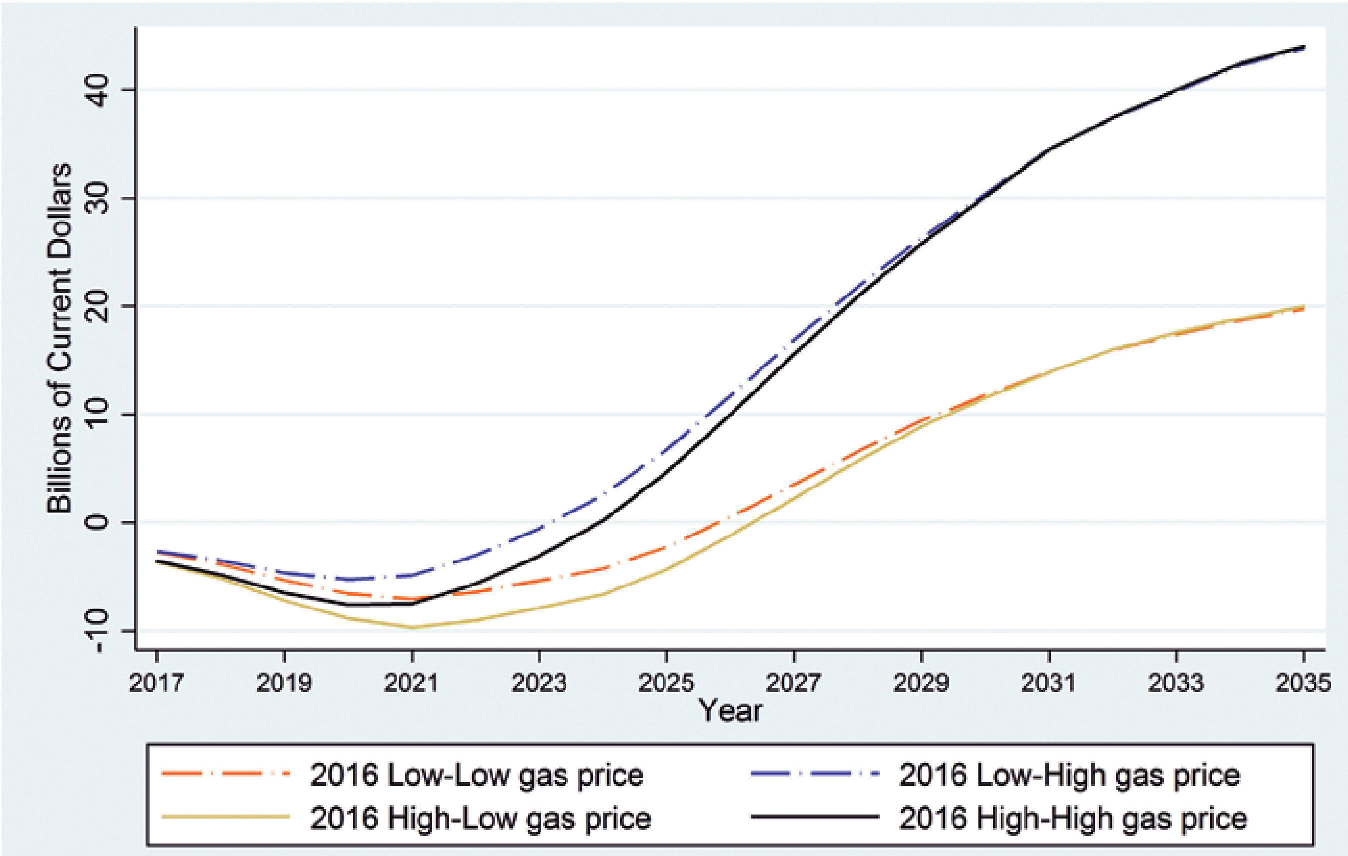


Figure 8.25. Difference in Disposable Personal Income Between Baseline and Combined Regulatory Scenarios with Low and High Gasoline Prices.



of magnitude as the present value of fuel savings for the model year 2025 federal standards, but they are much more immediate in their occurrence.

Economists from Goldman Sachs were widely quoted as characterizing the consumer savings on fuel as the equivalent of a $100-125 billion tax cut in 2014 (Morath 2014). However, a year later, a Goldman Sachs economist was quoted as saying that the spending boost from lower gasoline prices has "fallen short of expectations" (Cox 2015). Another year later, an economist confessed to the New York Times that the economy-wide benefits of the lower oil and gasoline prices "failed to deliver the usual economic benefits" (Appelbaum 2016). More generally, the question has been raised as to why the sharp decline in oil and fuel prices in 2014-16 has not spurred a stronger U.S. recovery. The U.S. economic recovery since the Great Recession of 2007-9 has been quite slow by historical standards, indeed the slowest of any of the modern recessions studied by the National Bureau of Economic Research (Graham 2016; Seefeldt et al. 2013).

The major explanation that has been offered is that consumers are not behaving in the ways that economic models such as REMI assume. First, when consumers save money on gasoline due to lower fuel prices, they may respond by paying off their credit card debts and boosting their savings and investments. Consumer debt payments as a share of disposable income rose from 2012-2015 (Arora 2015). Since low-income consumers spend a higher fraction of their income on gasoline than high-income consumers, the behavior of low-income consumers needs to be studied carefully (Murphy, Plante, and Yücel 2015).

On the other hand, the REMI model assumption that consumers spent 100% of the savings is not far off from the standard estimate that Americans save only about 5% of every dollar that they earn (Soper, Olson, and Townsend 2015; Skowronski 2015). Additionally, recent studies of credit and debit card holders find that consumers are spending between 80% and 100% of the gasoline savings induced by lower fuel prices (Farrell and Greig 2015;

Gelman et al. 2016). Some consumers may not yet be convinced that the savings are permanent and thus some of the transitory income is used to pay down debts. For application to the regulations we are studying, there is no particular reason for consumers to expect the savings to be temporary, though the magnitude may be seen as uncertain.

There is another body of literature suggesting that motorists are plowing a substantial amount of the savings back into gasoline by purchasing premium gasoline (higher-octane, higher-priced blends) (Hastings and Shapiro 2013; Appelbaum 2015). The surge in sales of premium gasoline is considered ill-informed by many experts, as most vehicles designed to run on regular gasoline will not perform any better—or have lower maintenance costs or burn more cleanly—when operated with premium gasoline (Stepp 2016). About 70% of passenger vehicles on the road were designed to run on regular gasoline (Friedman 2016). AAA has undertaken a public education program to discourage consumers from spending money on purchases of premium gasoline (Blumenthal 2016). From a macroeconomic perspective, it seems unlikely that a shift from regular to premium gasoline will have much of a favorable economic effect. Once again, this consumer response may also be a short-term effect, but it needs to be studied further.

While it is tempting to draw parallels between the recent savings in gasoline expenses due to lower oil and gasoline prices and the long-term accumulated savings in fuel expenses that federal agencies predict will result from federal CAFE and GHG standards, the two scenarios have some strong differences when compared. The recent savings in gasoline expenses are occurring in an economy that is also experiencing a rapid decline in oil prices and a sluggish recovery from the Great Recession. The federal regulations under study are not expected to have a large effect on the global price of oil, primarily because the U.S. has a much diminished share of the global oil market than it did several decades ago. In addition, gasoline savings from the federal standards will accumulate slowly and gradually over many years of vehicle use, with no connection to the Great Recession. Thus, a dollar of gasoline savings may have a different impact on the U.S. economy in 2014-15 than it will from 2017-2035.

8.72 Unresolved Issues Related to Effects of Gasoline Savings on Oil Imports and U.S. Production of Oil

The structure of REMI and some of its key inputs were designed prior to the fundamental changes in energy markets that caused the sharp decline in oil and gasoline prices. For example, the default settings in REMI assume that the U.S. economy imports about 52% of its oil (in 2015 EIA put the U.S. oil-import share at 24%). Moreover, the geographic origin of U.S. oil imports has changed, as Canada and Mexico—both economies that are integrated with the U.S. economy—now account for a majority of U.S. oil imports (EIA 2016; Wilson 2011; Fergusson 2011). In fact, some of the "oil imports" that remain are simply foreign users of U.S. oil refineries, since the product of the refiners (e.g., diesel fuel) is then exported to Europe or elsewhere in the world. Those "imports" to U.S. refiners would not be affected by the regulations under study. The U.S. is already a net exporter of natural gas and some forecasts suggest that the U.S. could become a net exporter of oil prior to 2025. In other words, the magnitude and nature of "oil imports" is changing in the U.S., and thus the structure of REMI needs to be modernized to reflect these changes.

Another key assumption of REMI is that a substantial share of the supply chain for U.S. oil and gas production is imported (e.g., some of the steel and chemicals used by U.S. oil producers are imported). However, REMI's supply chain for oil and gas has not yet been updated to reflect the unconventional development practices that were pioneered in the U.S. and have become widespread in the U.S. industry in the last five years, such as horizontal drilling and multi-stage hydraulic fracturing with large quantities of water, sand, and chemicals.

We performed two sensitivity analyses to determine how sensitive the REMI results might be to changes in the analytic treatment of oil imports. When we compared two extremes—all of the gasoline savings lead to oil-import reductions vs. all the gasoline savings lead to U.S. oil production cuts—our results did change significantly (results not reported here). Thus, we recommend future research to modernize the structure of REMI to reflect new energy production practices in the U.S., including forecasts of how they are expected to evolve in the years ahead.

8.73 The Need to Incorporate Revenue Recycling from Imports

A basic feature of most economic input-output models of entire economies is that cash outlays for imported goods and services permanently leave the economy under study. Sectors with large import shares in their supply chains, other things equal, have smaller multipliers than sectors whose supply chains draw entirely from producers in the domestic economy. This is certainly not a unique feature of REMI but it is likely to have influenced the results of our modeling significantly.

We confronted the issue twice, once in the case of oil imports and again in the case of the stimulus of the automotive supply chain. In the case of oil imports, it is well known that much of the money paid for foreign oil is recycled back into the U.S. economy—directly or indirectly—when foreigners purchase U.S. goods and services or invest in U.S. financial assets such as Treasury securities, stocks, and mutual funds (M. Higgins, Klitgaard, and Lerman 2006). Today, the largest sources of U.S. oil imports are Mexico and Canada, yet those two economies are highly integrated with the U.S. economy.

In the case of automotive supply chains, cash is paid to German, Korean, and Japanese suppliers of parts, but REMI assumes that none of it is recycled back into the U.S. economy. In reality, a share of the revenues paid to foreign parts suppliers are reinvested back into the U.S. economy, for the same reasons described in the case of oil imports. Of particular concern are the important roles that Mexico and Canada play in the U.S. automotive industry (Swiecki and Menk 2016). REMI treats Mexico and Canada as foreign economies when, in fact, the U.S., Mexican, and Canadian economies are highly integrated. That was of course the entire point of the North American Free Trade Agreement (NAFTA) (Dziczek et al. 2017).

We performed some preliminary exploration to determine whether oil-revenue recycling into U.S. capital markets would significantly change our results. REMI has a capital-market sector with developed links to employment, GDP, and income. When we allowed petrodollars from U.S. imports to recycle back into U.S. capital markets, the results of our REMI model changed noticeably, and pushed the long-term macroeconomic benefits of the regulation many years out into the future (results not reported here). This result is due to the expectation that the federal regulations of fuel economy and GHG emissions will reduce the volume of recycled petrodollars entering the U.S. economy. For future research, we suggest a more in-depth analysis of global capital markets and the manner in which petrodollars circulate within these markets.

Recycling of the auto-import dollars raises some similar and distinct issues. The roles of Canada and Mexico as integrated economies are again important, like it was with oil imports. However, car exporters in Germany, Korea, and Japan are quite different than the main oil-exporting countries (e.g., Saudi Arabia, Venezuela, and Nigeria). Although the issues are analytically challenging, we encourage future research to capture more realism about the U.S. economy by building in some recycling of dollars paid for imported goods and services.

An alternative analytic approach is to work with an input-output model of the global economy, one that has sufficient regional differentiation and interactions to shed light on these issues. We believe that the global approach is also worthwhile to pursue.

9. VEHICLE SALES ANALYSIS

While the REMI model is able to predict macroeconomic effects based on a complex set of economic and demographic interactions, it is limited in its ability to predict real world market dynamics. We discussed several of these shortcomings in section 8. An additional limitation is its inability to model consumer perceptions and behavior. In the REMI model, consumers respond to an increase in the price of a vehicle by simply demanding less of that commodity, as calculated via an elasticity of demand. Yet, as the energy economics literature reveals (see section 4), consumers tend to have more complex decision making processes than a simple elasticity can capture, especially within markets for energy efficient commodities. Thus, for estimates of new vehicle demand we elected to build a detailed set of procedures that can more fully and accurately account for consumer perceptions and behavior, not only in relation to the price of vehicles but also as it pertains to the price of gasoline, perceptions of resale value, and other important considerations. We describe these procedures and discuss the implications of our results in this section.

The volume of new vehicle sales is a commonly reported macroeconomic indicator but, as we explained earlier in the report, it is also a crucial input to environmental, safety, and cost-benefit analyses. Changes in the volume of new vehicle sales impact the pace of penetration of cleaner and safer vehicles into the fleet; they are also central to gauging the magnitude of regulatory costs and benefits from a societal perspective. Thus, our analytic work should assist agencies performing societal cost-benefit analyses as well as offer a supplemental macroeconomic perspective.

9.1 Baseline and Time Horizon

As in the REMI modeling, results of the TCO modeling are reported for the 2017-2035 period, using the 2016 federal standards and the 2017 ZEV requirements as the baseline. However, the estimated impacts on new vehicle sales are meaningful only through 2025, since we assume that the federal and state regulations are unchanged after 2025 and since we assume no lag between when a vehicle price increase occurs and when effects on new vehicle sales occur. However, the TCO results account for consumer perceptions over the entire lifetime of each model year. For example, for consumers considering a new vehicle in 2025, the TCO accounts for consumer perceptions of fuel prices, fuel savings, and resale value throughout the entire vehicle lifetime (maximum of 30 years for cars and 37 years for trucks).

9.2 The Total Cost-Of-Ownership (TCO) Model

In order to capture the effects of the regulations on the volume of new vehicle sales, we need a modeling structure that accounts for both changes in new vehicle price and changes in vehicle operating costs and resale values due to new technology. We elected to use the same modeling structure that NHTSA has used in its RIAs for more than a decade, as that structure has been reviewed by the Office of Management and Budget and the Council of Economic Advisors and is familiar to the stakeholders and congressional staff interested in the regulatory issues. The structure is a total cost-of-ownership (TCO) model, looking at the total cost for consumers over the anticipated life of the vehicle.

Specifically, we assume that the percentage change in new vehicle sales, due to regulation, is triggered by a change in the "net" price premium and the price elasticity of demand for new vehicles. The "gross" price premium is the initial price increase attributable to the incremental costs of producing vehicles with fuel-saving technology. The "net" price premium is a complex construct: it is the gross price premium minus the present discounted value of a stream of cash flows related to vehicle purchase costs (sales taxes, insurance premiums, and loan financing fees/payments), vehicle operating costs (energy expenditures), and the resale value of the vehicle (since a vehicle is typically resold at least once over its lifetime). See Appendix VIII for the specific algebraic expressions and a detailed discussion of how the TCO is built.

9.3 An Illustration of the TCO Model

The TCO model combines changes in the net price premium with the price elasticity of new vehicles to determine the impact of the regulations on volume of vehicle sales. The price elasticity of demand relates a percent change in price to the corresponding percent change in new vehicle demand (volume of new vehicle sales). While the literature typically defines price elasticity of demand in terms of gross vehicle price, we—like NHTSA—make the assumption that consumers care (at least to some extent) about the “net” price premium, since consumers will also be impacted by less immediate factors such as loan payments, energy costs (gasoline and electricity), and resale values when vehicle ownership changes. Thus, if regulation causes a gross vehicle price premium of $1,000 (e.g., for a mild hybrid system that saves fuel during vehicle operation), and if less immediate factors (e.g., diminished gasoline consumption) save the consumer $700 in present discounted value over the consumer’s time horizon, then the net price premium in the eyes of the consumer is $300.

If the average price of the vehicle was $30,000, the net premium of $300 will enlarge that price to $30,300, which is a 1% increase. If the price elasticity of demand is -1.0 (a standard estimate used by NHTSA and also used in our TCO modeling), that means that each 1% increase in vehicle price is associated with a 1% decline in the volume of new vehicle sales. The decline in new vehicle sales means that either (1) some consumers without a car delay purchasing their first car, and/or (2) consumers hold their existing car longer, and/or (3) consumers buy a used car instead of a new car. On a national basis, if about 17 million passenger vehicles are sold each year, a 1% decline in new vehicle sales corresponds to 170,000 fewer sales of new vehicles.

Notice that the impact of regulation on new vehicle sales can be positive or negative. If the net price premium is positive, the sales impact will be negative. But, if the net price premium is negative, the impact of regulation on new vehicle sales will be positive. This is not simply a mathematical nicety, since the federal agencies determined in 2012 that the present value of fuel savings due to regulation will be more than adequate to pay for the gross price premium associated with the 2017-2025 standards.

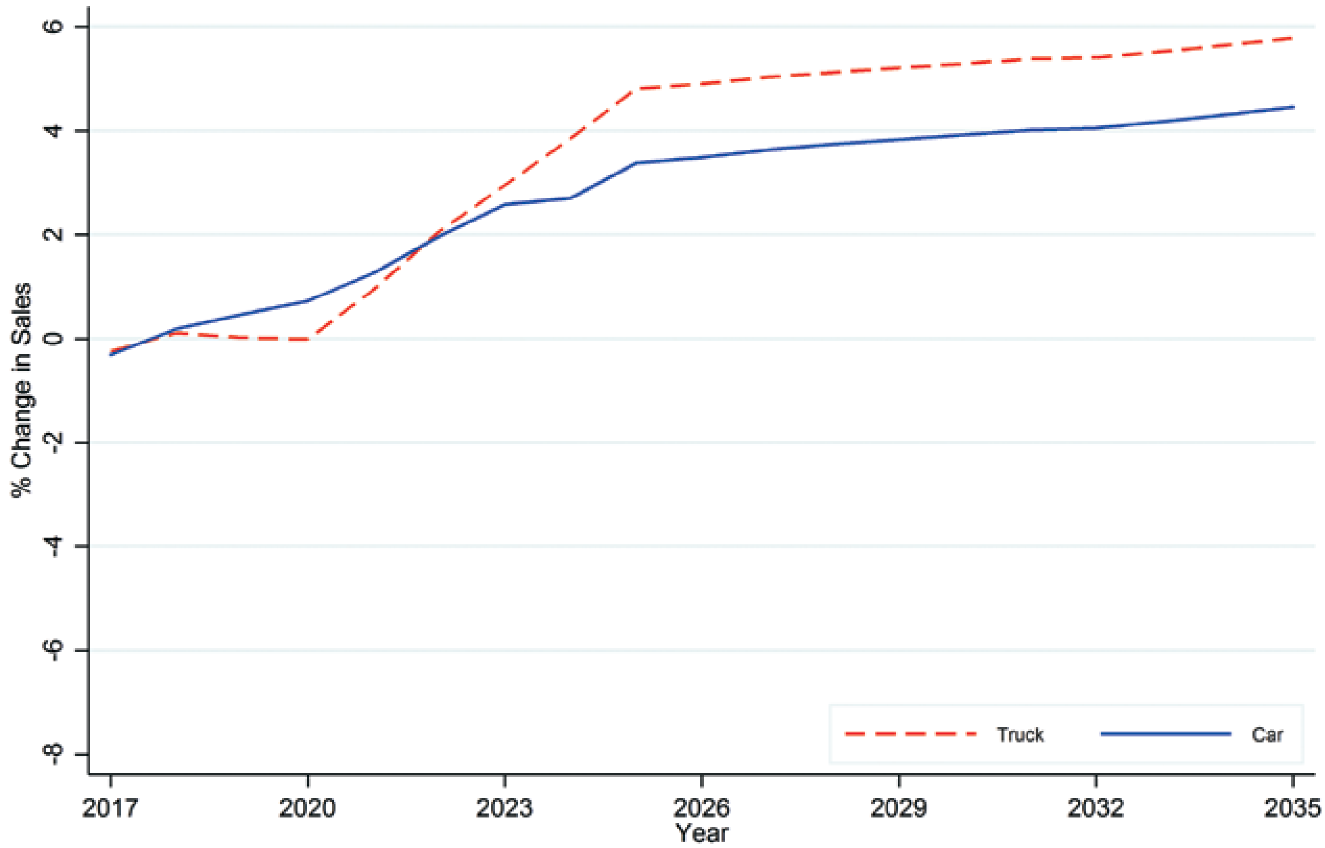
Our approach to consumer demand is conservative in the sense that we assume higher vehicle prices influence only the volume of new vehicle sales. Another form of consumer response, which we do not model, is an adjustment in the type of vehicle sold. For example, higher vehicle prices may induce consumers to purchase less expensive cars or cars with fewer options or upgrades (CAR 2015; 2016). The latter responses would impact the automotive supply chain even though the number of assembled vehicles is not altered. Additionally, the TCO analysis is based on the response of an average consumer to the changes in the price of an average car and an average light duty truck. The implication of this approach is that the only source of heterogeneity in the analysis is between cars and trucks. We do not account for heterogeneity across regions, manufacturers, make-model, or consumers. We discuss some additional assumptions in the sections that follow.

9.4 Results for the 2012 Perspective NHTSA

Figure 9.1 reports the percentage change in vehicle sales by model year (compared to a 2016 baseline) that can be attributed to the 2017-2025 standards using data and assumptions from what we call the 2012 NHTSA Perspective (i.e., our efforts to replicate the findings in NHTSA’s 2012 RIA). We find that the 2017-2025 federal standards have a predominantly positive effect on new vehicle sales. The sales impact on MY 2025 vehicles is larger for light trucks than for cars because the gross price premiums are approximately the same but the fuel savings are larger for light trucks than for cars. The effect is slightly negative in 2017, since one year of fuel savings is not enough to outweigh the gross price premium in 2017. For all of the other years through 2035, the effect of the 2017-2025 standards on new vehicle sales is positive. The positive effect slows its growth after 2025 because we assume no tightening of the federal standards in model years after 2025 and, therefore, no additional increase in the vehicle price premium. The weighted average change in vehicle sales over the period 2017-2025 is +1.5%, which is modestly smaller than the NHTSA estimate of +2.3%.

The magnitude of the positive effects for MY 2025 is +3.4% for cars and +4.8% for trucks for a combined 3.8% increase in total vehicle sales. This is not a trivial effect; a +4% increase in new vehicle sales on a base of 17

Figure 9.1. Percentage Change in Vehicle Sales due to Regulation by Model Year: 2012 Perspective NHTSA.



Notes: Reported is the percentage change in vehicle sales due to the 2017-2025 federal standards, using the total cost of ownership approach used by NHTSA in its 2012 RIA. Total cost accounts for purchase price, fuel savings, resale value, loan financing, auto insurance, and sales tax.

million vehicles corresponds to 680,000 additional vehicles. That is equivalent to the annual production volume of one of the larger U.S. automotive assembly plants.

9.5 Results for the 2016 Perspective, One Change at a Time

We now present results from the 2016 perspective, showing individually how various changes used in the 2016 perspective impact the results reported for the 2012 perspective.

9.51 Adjusted Gross Vehicle Price Premiums

Using results from NRC (2015a), we show how a small and large increase in the gross vehicle price premiums for cars and trucks impact new vehicle sales. The small increase is +11%; the large increase is +56% (both relative to NHTSA's 2012 input). Those adjustments represent "most likely" scenarios of different groups of experts within the NRC Committee. Those increases reflect the joint impact of new estimates of the fuel-saving effectiveness and resource costs for technological refinements to vehicles with an internal combustion engine. Section 8 provides a detailed discussion of the price premium. Also see Appendix VIII for a more detailed discussion of how we implemented the premium changes in the TCO.

Figures 9.2a and 9.2b show the effect of the premium increase on vehicle sales for cars and trucks, respectively; the 2012 perspective is shown in order to highlight the relative sales impact of the NRC adjustments. The pattern of results is intuitive. Relative to the 2012 perspective, the small premium increase has a small effect on car and truck sales while the large premium increase is sufficient to move the car-sales impact into the negative region up

Figure 9.2a. mpact of NRC Price Premium Adjustments on Car Sales by Model Year.

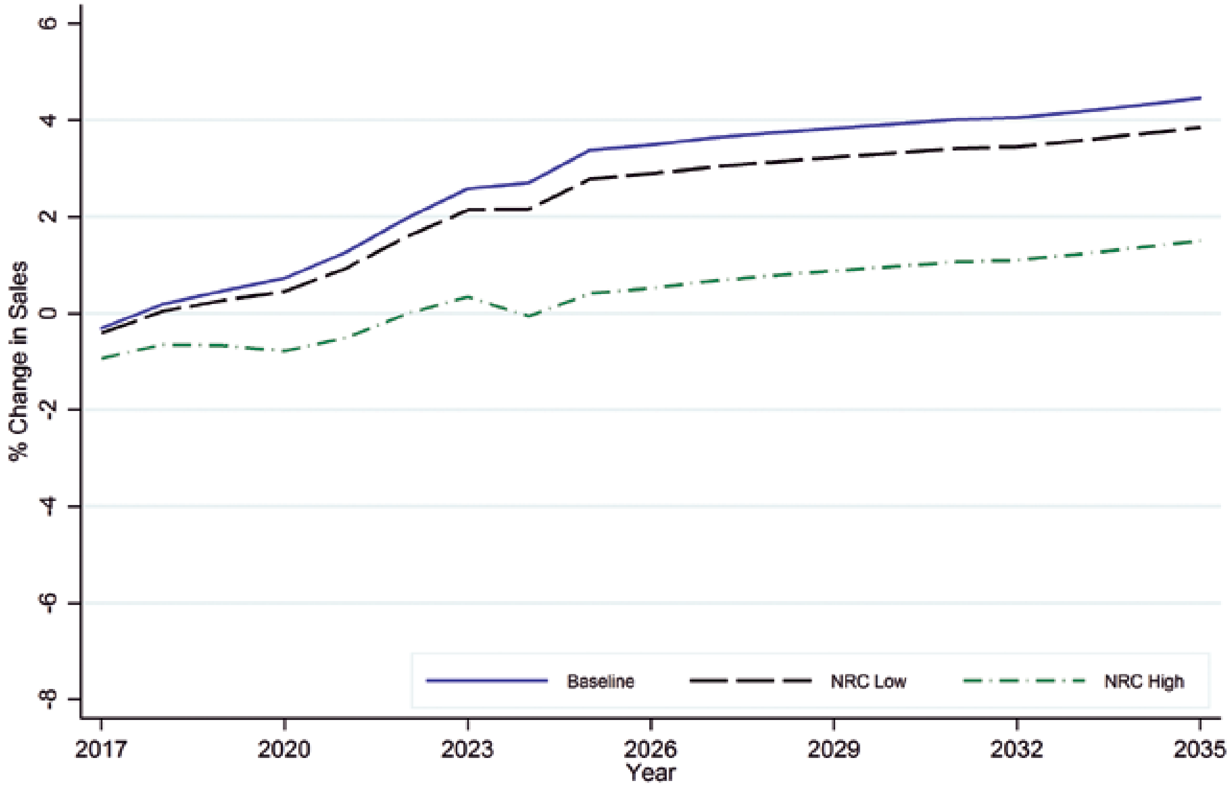
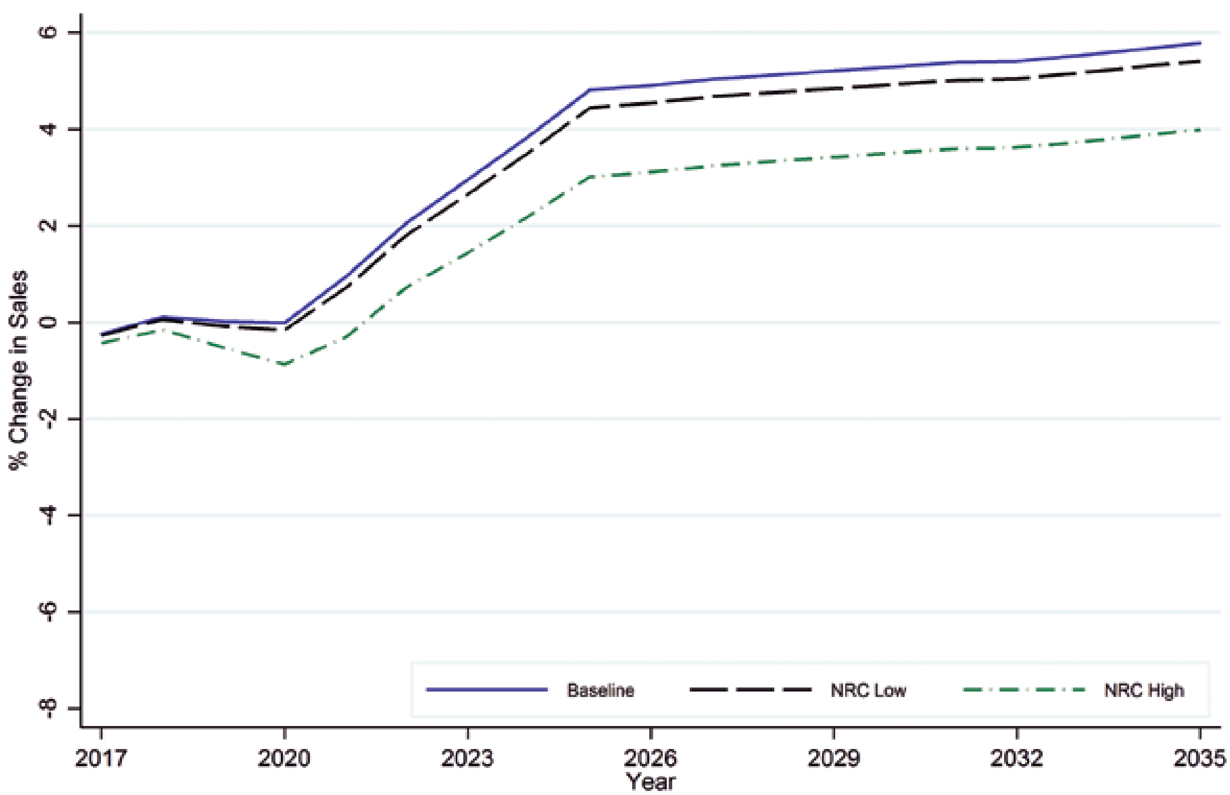


Figure 9.2b. Impact of NRC Price Premium Adjustments on Truck Sales by Model Year.



Note: Reported in both Figures 9.2a and 9.2b is the percentage change in vehicle sales due to the 2017-2025 federal standards based on various assumptions about vehicle price premiums. *Baseline* is vehicle price premium under the 2012 perspective using NHTSA's data. *NRC high* and *NRC low* represent the price premiums after accounting for the National Research Council's (NRC) 'high most likely' and 'low most likely' scenarios, respectively.

until about 2022. The car-sales impact remains positive for the remainder of the study period, but substantially less positive than in the 2012 perspective. For trucks, the large premium increase causes sales to decline through 2021, but the impact turns positive thereafter.

9.52 Add the Cost of the ZEV Requirements to the Federal Requirements

The ZEV requirements, which are applied in 10 states representing 30% of the new U.S. vehicle fleet, are modeled in several ways, each assuming different types of BEVs or different mixes of PHEVs and BEVs and thus somewhat different streams of technology costs. The ZEV premium is calculated in two ways: with a simulation approach (see section 7.3) and with the software COMET (see section 7.4). The simulation approach assumes the cost of the ZEV regulation will be allocated to cars nationally instead of being concentrated on the prices of cars sold in each of the ZEV states. We also assume that the ZEV compliance requirements do not affect manufacturers' strategy for complying with the federal programs. While this assumption simplifies the analysis, it results in over-compliance with the federal program and thus overestimates the incremental costs of the combined federal-ZEV regulations. The COMET approach addresses this latter problem and also allows for the ZEV premium to apply, separately, to both cars and trucks. The COMET approach maintains the assumption that ZEV costs are distributed nationally through vehicle prices.

Figures 9.3a and 9.3b report results for cars and trucks, respectively. The pattern of results reported in Figure 9.3a shows that the addition of the ZEV requirements to the 2012 perspective does not cause the overall impact on new car sales to become negative. However, inspection of Figure 9.3a reveals that accounting for the interdependence between the ZEV and CAFE mandates is important. Relative to the 2012 perspective (line denoted by "Baseline" in Figure 9.3a), the magnitude of the positive sales effects is dampened when we ignore the interdependence between ZEV and CAFE; from +3.4% for car sales to just over +2% in MY 2025. The COMET results show an increase in sales between 2017 and 2022, relative to the 2012 perspective, and a dampening of sales comparable to the simulation approach between 2026 and 2035.

The dampening effect is relatively large because the ZEVs (while they individually save large amounts of fuel) do not affect fuel consumption in the average new vehicle sold in the U.S. The corporate averaging features of the federal CAFE and GHG programs are such that each PEV produced due to the ZEV regulation allows vehicle manufacturers to produce one or more less fuel-efficient vehicles than they would have produced without the presence of the ZEV regulation.

The ZEV program also reduces truck sales relative to the 2012 perspective over the entire period under analysis (see Figure 9.3b). More importantly, sales are projected to decline over the 2017-2022 period before picking up again over the remainder of the study period. By 2025, truck sales are projected to be about +2% compared to approximately +4% in the 2012 perspective.

9.53 Consumer Valuation of Fuel Savings

In its 2012 analysis, NHTSA assumed that new-vehicle purchasers (1) project future fuel prices based on EIA forecasts, (2) value five years of fuel savings after purchase, which corresponds to NHTSA's assumption of the length of a car-loan agreement, and (3) perceive that they will capture 35% of the gross price premium for fuel-saving technology when the vehicle is resold after five years. The resale value is assumed to be unaffected by fuel price.

The 2016 perspective makes several changes. The consumer assumes flat fuel prices over the ownership period at the level projected at the time of vehicle purchase. The consumer's horizon on fuel savings is reduced from five years to three years or one year in alternative analyses. Resale value of fuel saving technology is equal to 55% of the present value of fuel savings (7% discount rate) from years six to 30 of the vehicle life, and varies based on fuel price scenario. All other inputs are the same as the 2012 perspective. The rationales and evidence supporting these changes are discussed in section 4.

Figure 9.3a. Impact of ZEV Regulation on Car Sales by Model Year.

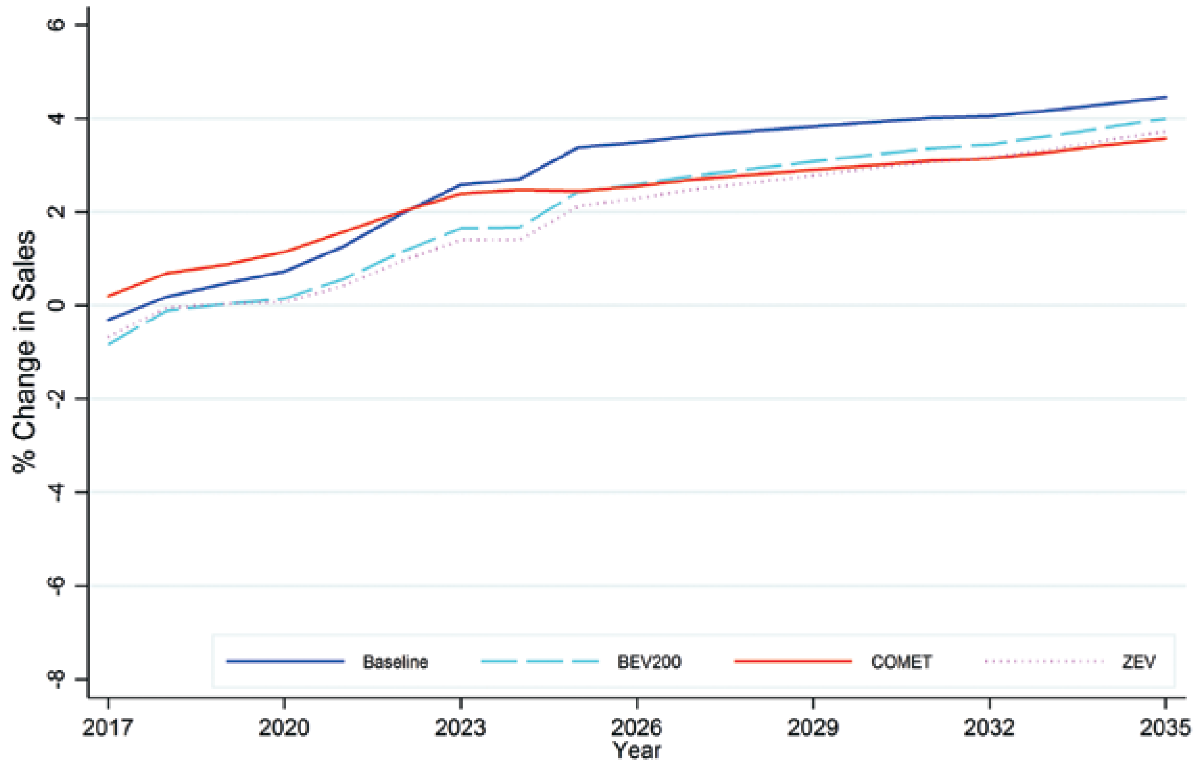
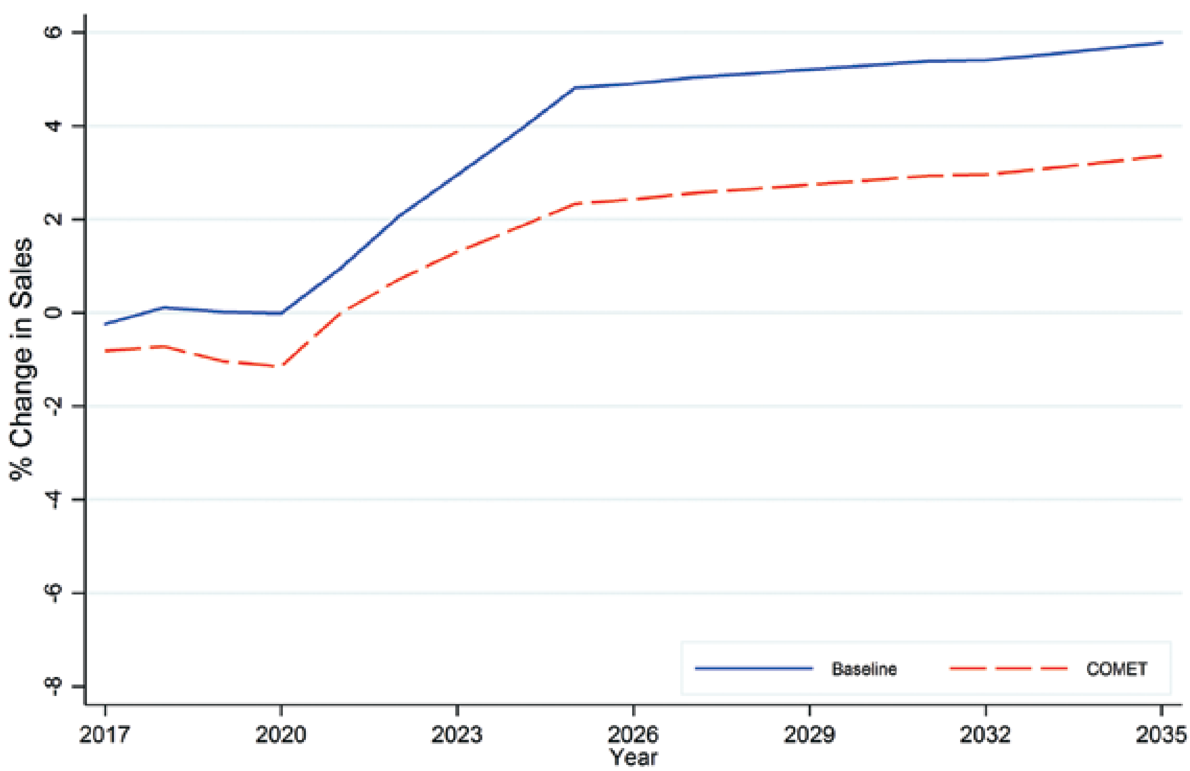


Figure 9.3b. Impact of ZEV Regulation on Truck Sales by Model Year.



Note: Reported in both Figures 9.3a and 9.3b is the percentage change in truck sales due to the regulatory programs under various assumptions about how the ZEV regulation is met. Baseline uses the price premium under the 2012 perspective using NHTSA's data, and omits the ZEV regulation. The other line shows the effect of the CAFE plus ZEV on truck sales using price premiums obtained from the *COMET* model. *COMET* assumes ZEV is satisfied with BEV75s. Notice also that the *COMET* premiums include some NRC adjustments.

The results in Figure 9.4a for cars show that the consumer's perception of fuel price change does not have a meaningful effect on the results, relative to the 2012 perspective. Reducing the valuation period for fuel savings has a large impact on the results, basically eliminating the positive sales effects (when the consumer values three years' worth of fuel) or producing a -3% sales effect in 2025 (if the consumer values only one year of fuel savings). The change in resale value works in the opposite direction: if the new-vehicle consumer perceives a higher resale value for the vehicle with superior fuel-saving technology, then the positive effects on new car sales climb by 2025 from under +3.4% to +6.4%. Note that these results all assume the 2012 fuel-price forecast, before the global change in energy markets.

The qualitative pattern of changes is the same for trucks; see Figure 9.4b. Changing the discount rate applied to future fuel savings has a smaller effect on the results than changing the number of years of fuel savings valued by the consumer. See Figure VIII.1 in Appendix VIII for vehicle sales impacts based on discount rates of 5%, 7% and 13% (the latter representing interest rates on credit card debt). We do not present results at 3% because, while 3% is an appropriate social discount rate for some applications of cost-benefit analysis, it is not relevant to modeling impacts of regulation on new vehicle sales in the automotive industry.

9.54 Lower Fuel Prices

Fundamental changes in global energy markets, including the "fracking" revolution in North America, have caused a sharp decline in oil and gasoline prices since 2012. Energy experts believe that lower oil and gasoline prices may persist for a long period of time. For example, EIA projected, in the reference case from 2012, that national gasoline prices in 2025 would be $3.90 per gallon (2010 $). In 2016, EIA's reference case forecast was $2.74 per gallon (2010 $).

The lower fuel prices impact the TCO model by reducing the savings in fuel expenditures experienced by motorists. When a consumer considers whether to purchase a hybrid or plug-in vehicle, the investment looks more attractive when fuel prices are $4 per gallon than when they are under $3 per gallon.

Figures 9.5a and 9.5b show that the lower fuel-price projection causes a meaningful change in the pattern of new vehicle sales. For cars and trucks, sales impacts are negative for several years before they turn positive. In 2025, instead of +3% impact on car sales, the boost is only about +1%. For truck sales, the boost of +5% in 2025 is shaved to about 3%.

Figures VIII.2 and VIII.3 in Appendix VIII report a single-variable sensitivity analysis using EIA's high, reference, and low fuel-price projections from 2016 for cars and trucks, respectively. The changes in estimated impacts on new vehicle sales are substantial.

9.55 Updated Information on Miles of Vehicle Travel

In the TAR (2016), NHTSA presents a rich new database on vehicle miles of travel by vehicle age. These data are based on actual odometer readings of a large sample of vehicles covering 16 model years (2000-2015). Consequently, the new data have a significant advantage over the previously used VMT data obtained from NHTSA's 2009 Household Travel Survey. Compared to the data used in 2012, the new VMT estimates are slightly larger in the early years of vehicle ownership but substantially lower in later years and for the entire vehicle lifespan. Use of the new VMT data, which changes fuel-savings estimates, does not have a noticeable impact by itself on the volume of vehicle sales (results not reported).

9.56 Raise the Average Rate on Car Loans

In 2012, NHTSA assumed an average interest rate on car loans of 5%. The 2016 perspective raises that rate to 7%, which is aligned with the 7% annual discount rate applied to future fuel savings. The higher interest rate is supported by the fact that the long-term historical average is about 7% (Allcott and Wozny 2014). Moreover, loan rates for the subprime borrower tend to be higher than average, and those borrowers may be particularly

Figure 9.4a. Impact of Consumer Valuation of Fuel Savings on Car Sales by Model Year.

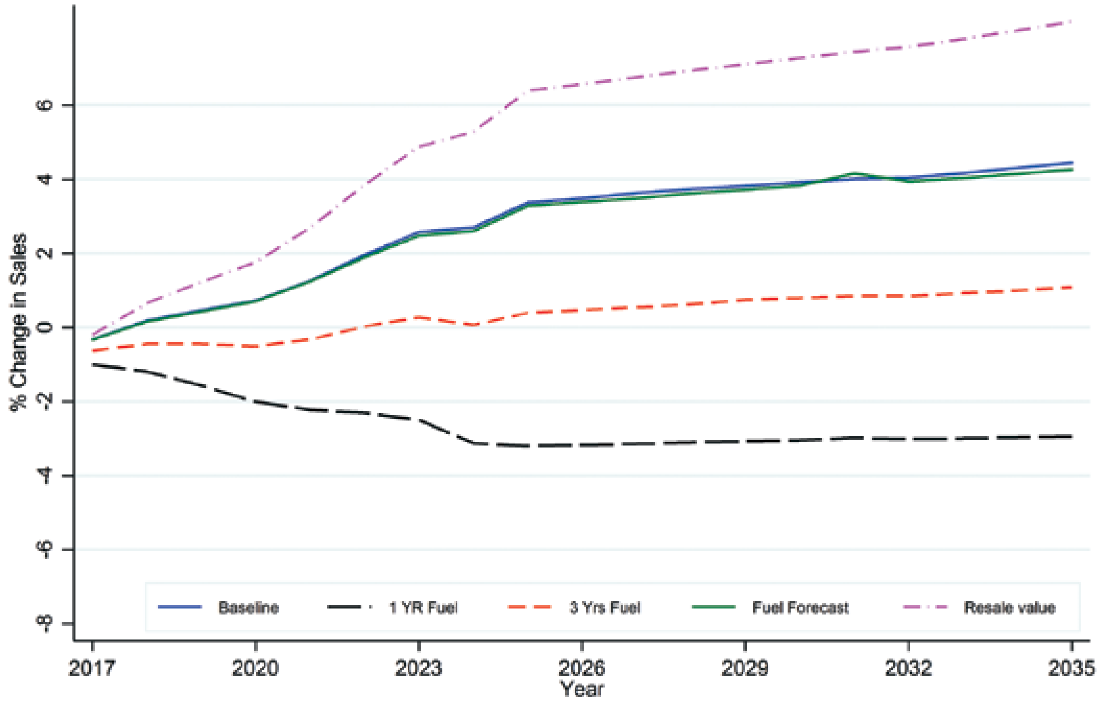
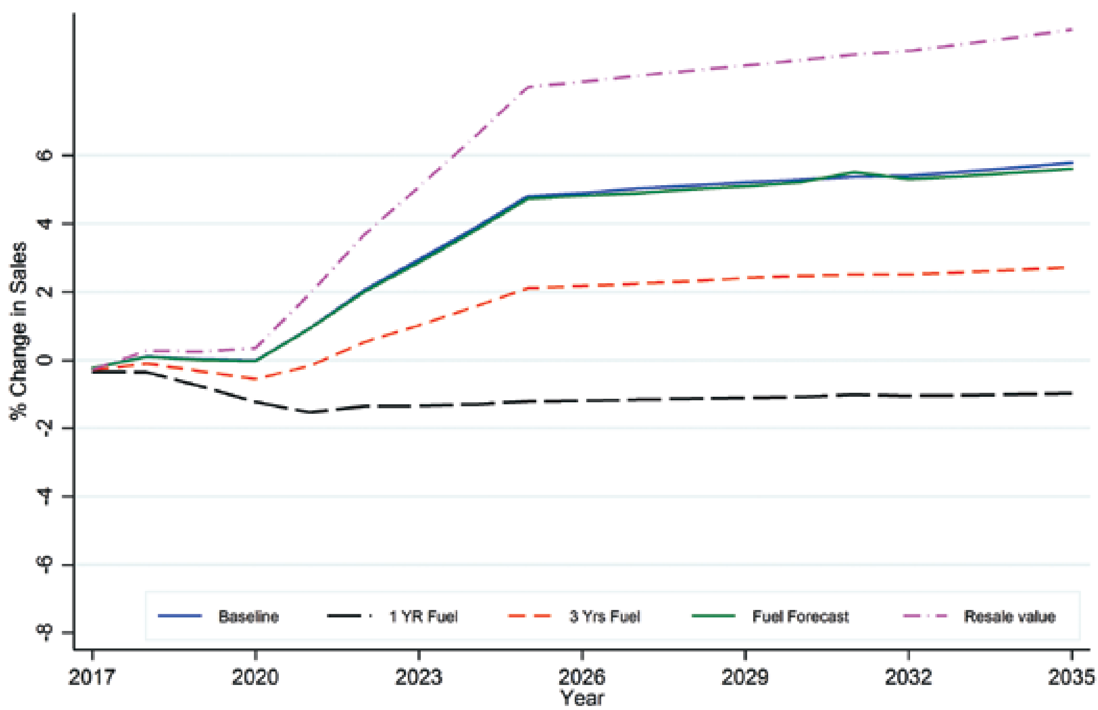


Figure 9.4b. Impact of Consumer Valuation of Fuel Savings on Truck Sales by Model Year.



Note: Reported in both Figures 9.4a and 9.4b is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about how consumers value fuel savings. *Baseline* uses NHTSA's data and thus assumes consumers value five years' worth of fuel savings, perceive resale value of fuel-saving technology to be 35% of gross price premium, and perceive future fuel prices equal to the AEO projections. *1 YR fuel* and *3 YR fuel* are the same as the baseline except that consumers only value 1 and 3 years of fuel savings, respectively. *Fuel forecast* is the same as the baseline except the consumers are assumed to take today's fuel price as the forecast of tomorrow's fuel price. *Resale* is the same as baseline except that resale value is equal to 55% of the present value of fuel savings from years 6 to 30 of the vehicle's life. Discount rate is 7%.

Figure 9.5a. Impact of Regulation on Car Sales by Model Year Under Different Fuel Prices.

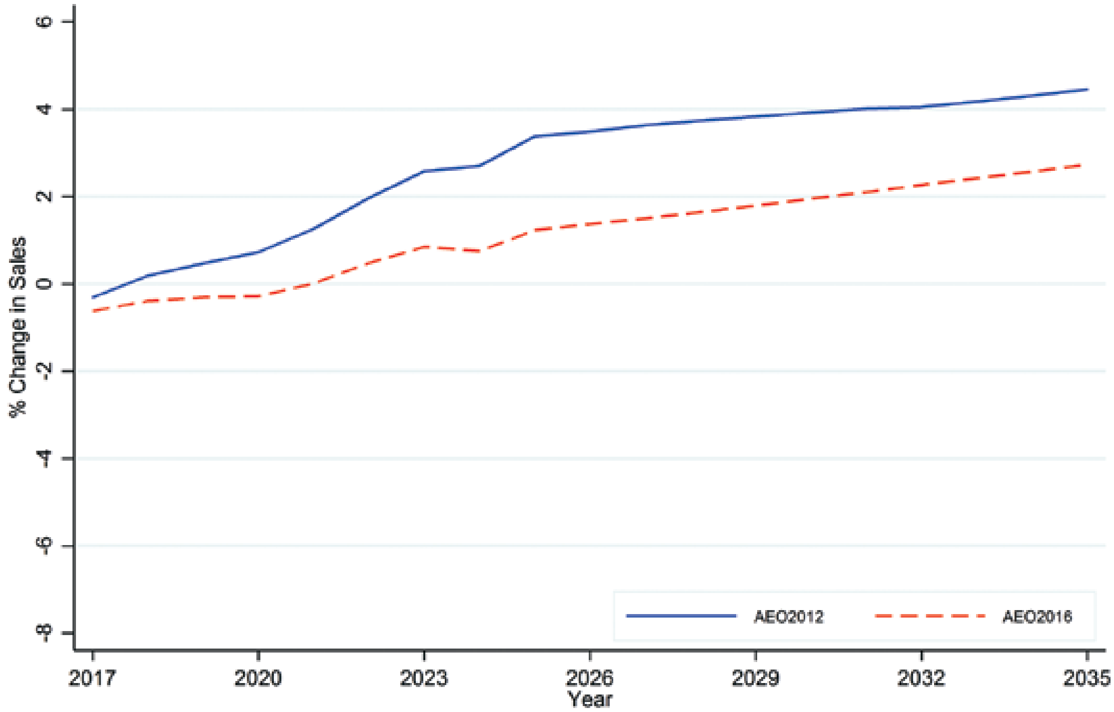
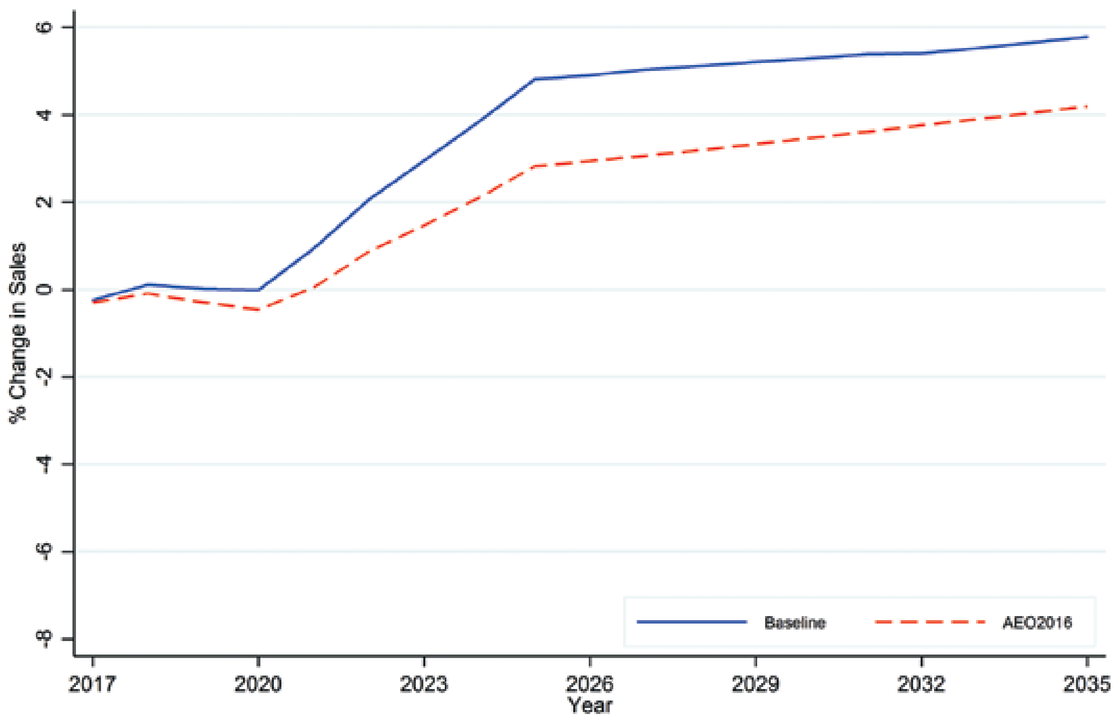


Figure 9.5b. Impact of Regulation on Truck Sales by Model Year Under Different Fuel Prices.



Note: Reported in both Figures 9.5a and 9.5b is the percentage change in vehicle sales due to the regulatory programs, using the reference fuel price published in the 2012 and 2016 annual energy outlook (AEO). *AEO2012* uses NHTSA's data and thus uses fuel price from the AEO2012. *AEO2016* is the same as AEO2012 except that fuel price projections are from the 2016 AEO.

sensitive to vehicle price increases or declines in the monetary value of fuel savings. The Federal Reserve Board has recently raised interest rates and has announced plans for additional raises in the future. Changing the loan rate from 5% to 7% does not have a meaningful effect on the sales results (results not reported).

9.6 The 2016 Perspective: Making Multiple Adjustments Simultaneously

Now that we have explored the effect of each change individually, we present the 2016 perspective with all of the analytic changes made at once. Figures 9.6a and 9.6b present the sales impacts for cars and light trucks, respectively, assuming the 2016 Low Perspective vehicle price premium. Figures 9.7a and 9.7b use the 2016 High Perspective vehicle price premium. All of the figures also include a solid curve which represents the results from the 2012 perspective. All of the results except the 2012 perspective (which serves as the baseline) include the impact of the ZEV program.

Since assumptions about consumer valuation exert a strong impact on the results, the figures are constructed for different consumer perceptions of the value of fuel savings and of the future resale value of fuel-saving technology. The most optimistic 2016 results (based on five years of fuel savings, a perceived capture of 100% of future discounted fuel savings through resale value, and a 2016 Perspective Low price premium) put the 2025 impact on sales at +1% for cars and +5% for trucks (the latter result is similar to the 2012 perspective); see Figures 9.6a and 9.6b. In contrast, the most pessimistic 2016 results (based on one year of fuel savings, a perceived 0% capture of the value of technology at resale, and a 2016 High Perspective price premium), put the 2025 impact on sales at -11% for cars and -5% for trucks; see Figures 9.7a and 9.7b.

The most plausible results may be those represented by the lines labeled "2016 high," "2016 medium," and "2016 low." At the 2016 Perspective Low price premium (Figure 9.6a), the 2025 impact on new car sales is estimated at roughly -3%, and -5%, depending on how fuel savings are valued by the consumer. At the 2016 Perspective Low price premium (Figure 9.6b), the results for trucks vary (+1%, 0, or -1%), depending on how the fuel savings are valued by the consumer. At the 2016 Perspective High price premium (Figure 9.7a and 9.7b), the 2025 results for cars and trucks are uniformly negative; -6% and -8% for cars and -1% to -3% for trucks.

9.7 The 2016 Perspective: Relaxing Some ZEV Adjustment Assumptions

The results for cars tend to be more negative than the results for trucks for several reasons: the average buyer of a light truck has been assumed to be equally interested in a gallon of future gasoline savings compared to the average buyer of a car; the technology costs for light trucks are assumed to be only slightly larger than the technology costs for cars; the costs of the ZEV program, which will cause some trucks as well as cars to be electrified, have been allocated entirely to the car fleet; and the ZEV costs are added without accounting for the interdependence between ZEV and CAFE.

9.71 CAFE ZEV Interdependence

The validity of some of the car vs. truck assumptions are open to question, and are a fruitful topic for future research. Here we relax the last two assumptions by using COMET to account for the ZEV cost premium. Specifically, we illustrate the sales impacts on cars and trucks after accounting for the fact that ZEV compliance makes it cheaper to comply with CAFE. We account for this interdependence by relying on the price premium estimated by the COMET model. The COMET model also assumes that manufacturers will implement ZEV technology on both cars and trucks.

Figure 9.8a shows the sales impact on cars for four scenarios: 2012 perspective, high and low 2016 perspectives, and COMET 2016 perspective. While all of the 2016 perspectives show negative sales impacts, the COMET 2016 perspective shows that accounting for the interdependence between ZEV and CAFE results in a smaller sales effect on cars. The 2016 COMET results for trucks track the 2016 high perspective closely up to 2022 before diverging over the rest of the period; COMET sales effects are larger in absolute terms and negative over most of the study period (see Figure 9.8b).

Figure 9.6a. Percentage Change in Car Sales Due to Regulation by Model Year, 2016 Perspectives, Low Price Premium.

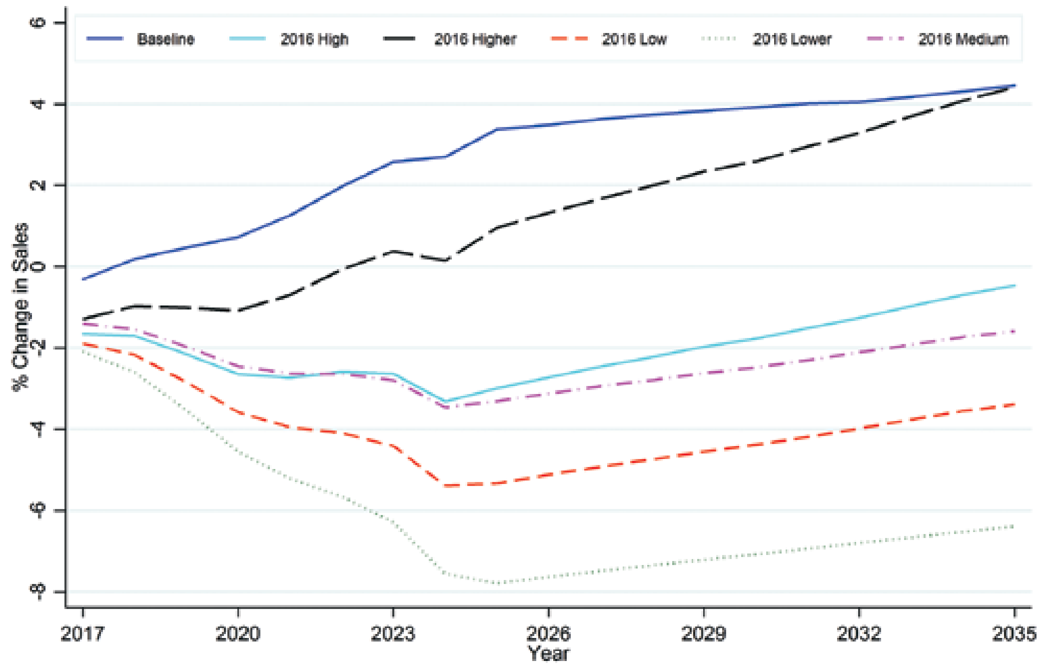
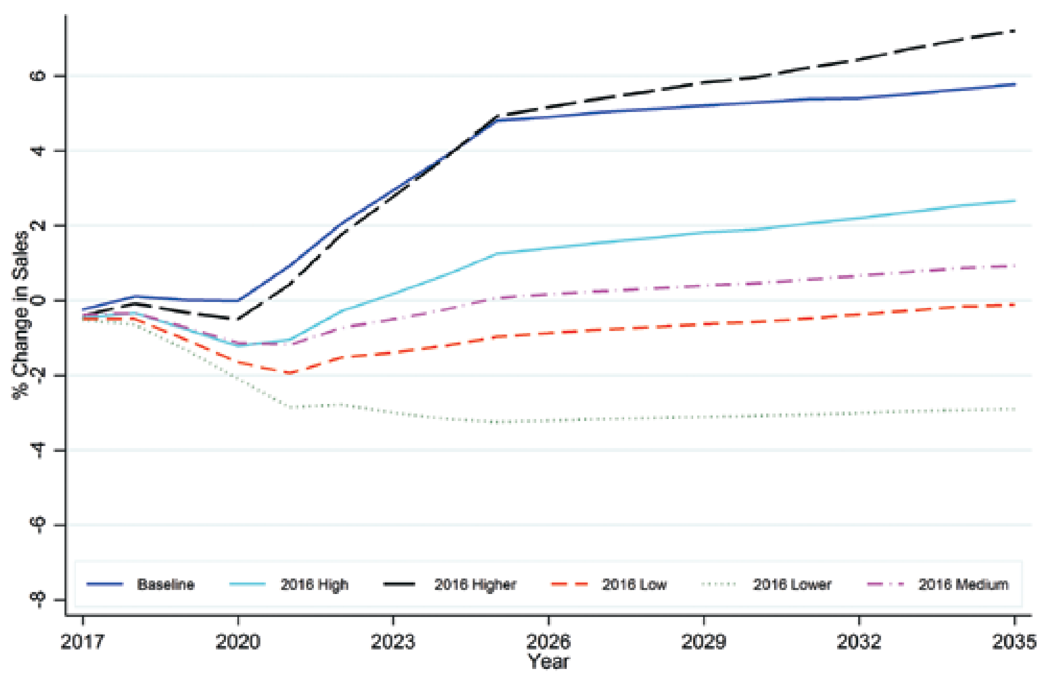


Figure 9.6b. Percentage Change in Truck Sales Due to Regulation by Model Year, 2016 Perspectives, Low Price Premium.



Note: Reported in both Figures 9.6a and 9.6b is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about how consumers value fuel savings. *Baseline* is based on NHTSA's 2012 data; it assumes that consumers value five years' worth of fuel savings, perceive resale value equal to 35% of gross price premium, and perceive future fuel price equal to the AEO projections. The remaining lines are based on 2016 data, but vary consumer valuation of fuel savings. *Lower, Low, Medium, High,* and *Higher* assume the consumer values one, three, three, three and five years of fuel savings, respectively. *Low* and *Lower* sets perceived incremental resale value to zero. *High* and *Higher* sets perceived resale value equal to 55% and 100% of the present value of fuel savings from years 6 to 30 of the vehicle's life, respectively. *Medium* sets the incremental resale value to 35% of the gross premium. Gross price premium is equal to the NHTSA 2012 projections in the baseline. All other lines are based on the low price premium scenario; i.e., NHTSA 2012 plus DOE estimate of ZEV plus NRC 'low most likely' adjustment for Figure 9.6a, NHTSA 2012 plus NRC 'low most likely' for Figure 9.6b.

Figure 9.7a. Percentage Change in Car Sales Due to Regulation by Model Year, 2016 Perspectives, High Price Premium.

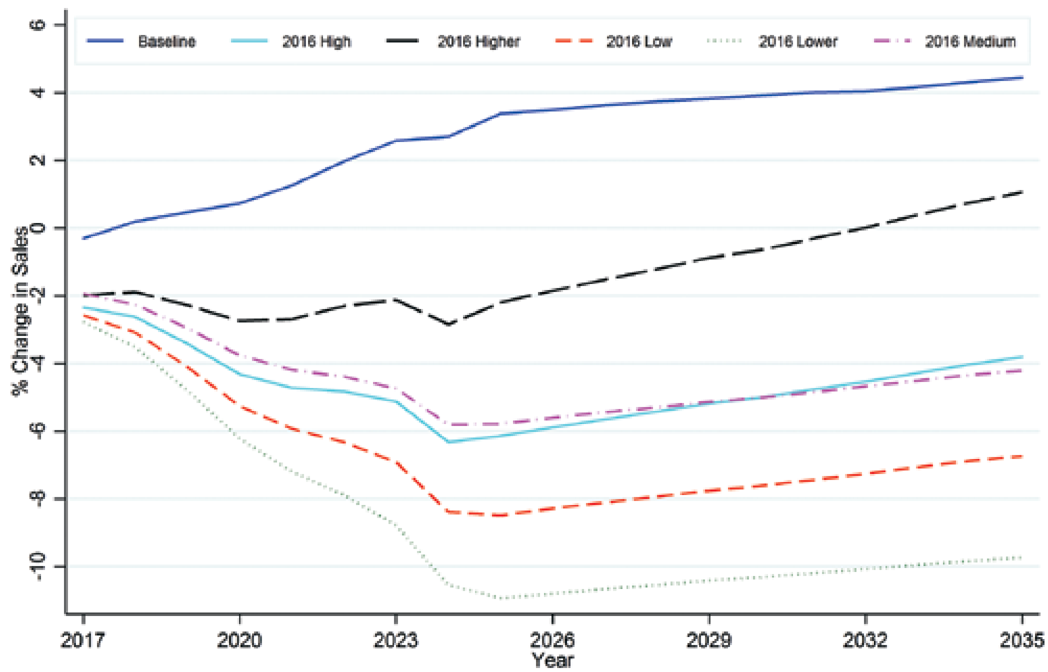
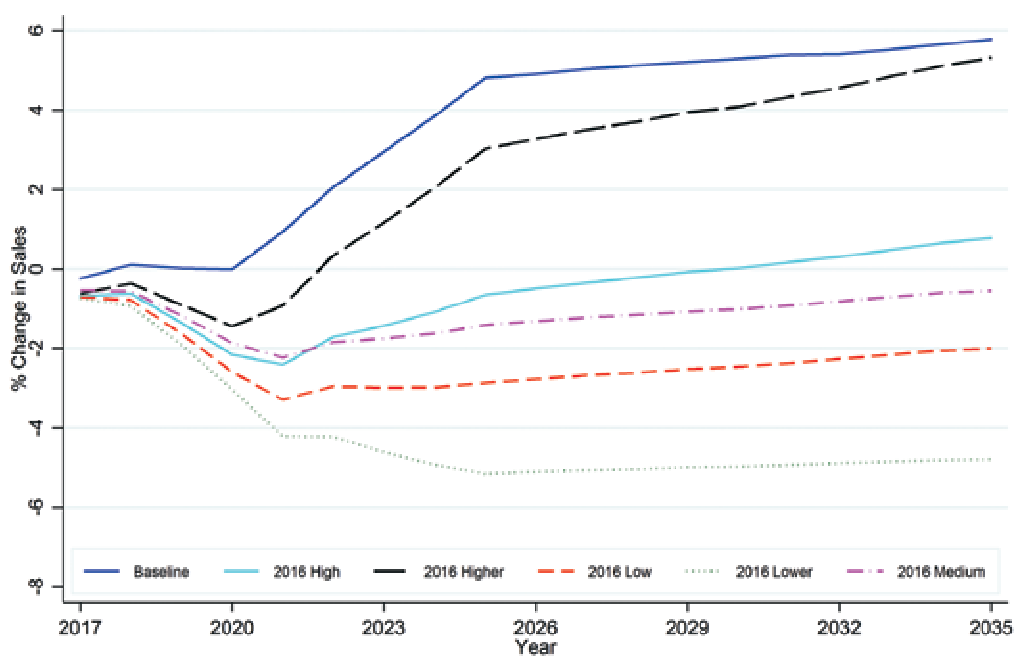


Figure 9.7b. Percentage Change in Truck Sales Due to Regulation by Model Year, 2016 Perspectives, High Price Premium.



Note: Reported in both Figures 9.7a and 9.7b is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about how consumers value fuel savings. *Baseline* is based on NHTSA's 2012 data; it assumes that consumers value five years' worth of fuel savings, perceive resale value equal to 35% of gross price premium, and perceive future fuel price equal to the AEO projections. The remaining lines are based on 2016 data, but vary consumer valuation of fuel savings. *Lower, Low, Medium, High,* and *Higher* assume the consumer values one, three, three, three and five years of fuel savings, respectively. *Low* and *Lower* sets perceived incremental resale value to zero. *High* and *Higher* sets perceived resale value equal to 55% and 100% of the present value of fuel savings from years 6 to 30 of the vehicle's life, respectively. *Medium* sets the incremental resale value to 35% of the gross premium. Gross price premium is equal to the NHTSA 2012 projections in the baseline. All other lines are based on the low price premium scenario; i.e., NHTSA 2012 plus DOE estimate of ZEV plus NRC 'high most likely' adjustment for Figure 9.7a, NHTSA 2012 plus NRC 'low most likely' for Figure 9.7b.

Figure 9.8a. Percentage Change in Car Sales by Model Year; Illustration of CAFE/ZEV Interdependence.

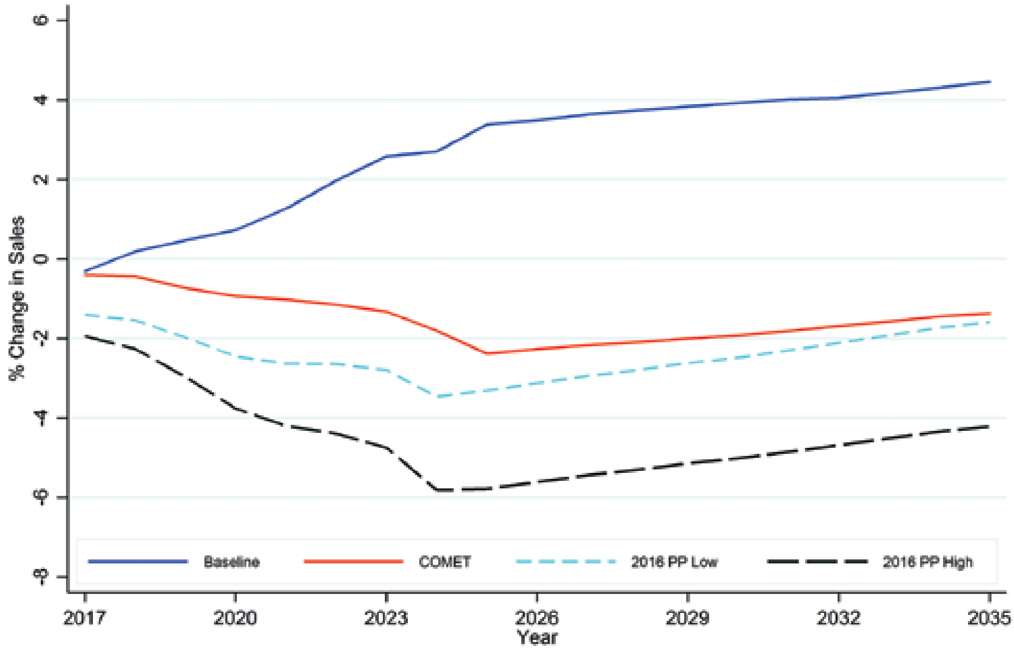
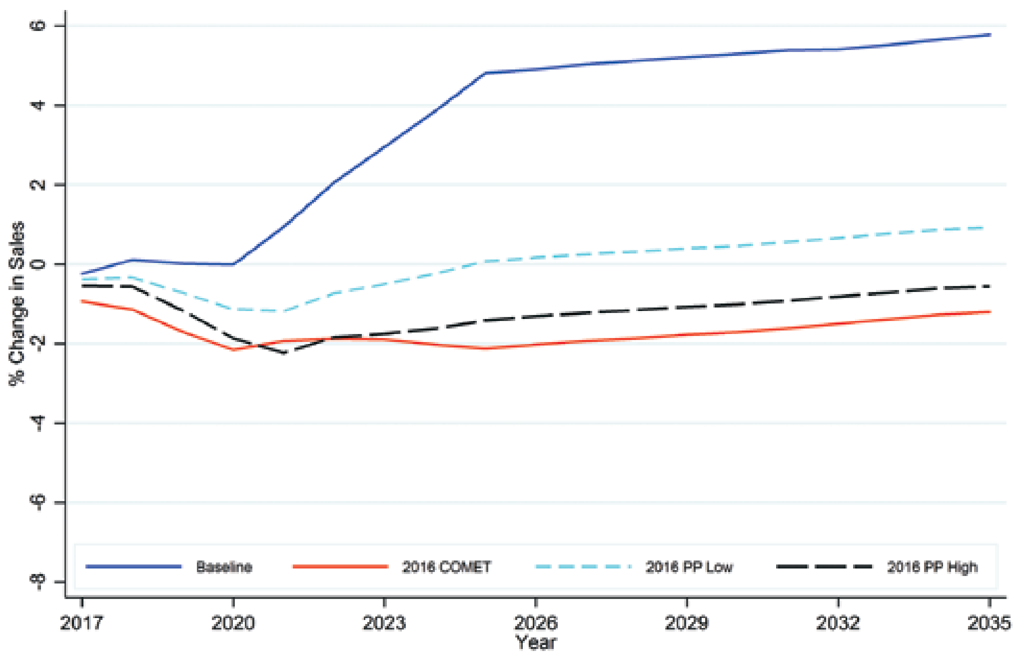


Figure 9.8b. Percentage Change in Truck Sales by Model Year; Illustration of CAFE/ZEV Interdependence.



Note: Reported in both Figures 9.8a and 9.8b is the percentage change in vehicle sales due to the regulatory programs based on our four perspectives. *Baseline* is based on NHTSA's 2012 data, and represents the 2012 perspective. The remaining lines represent the alternative 2016 perspectives. COMET accounts for the interdependence between CAFE and ZEV while the other 2016 perspectives do not account for this interdependence. Consumer valuation of fuel savings differs between the 2012 and 2016 perspectives: *Baseline* assumes that consumers value five years' worth of fuel savings, perceive resale value equal to 35% of gross price premium, and perceive future fuel price equal to the AEO projections. The 2016 perspectives assume the consumer values three years of fuel savings, perceive future fuel price equal to fuel price at time of vehicle purchase, and perceive the incremental resale value to equal 35% of the gross premium. Gross price premium is equal to the NHTSA 2012 projections in the *baseline*; NHTSA 2012 plus DOE estimate of ZEV plus NRC 'low most likely' adjustment in *2016 PP Low*; and NHTSA 2012 plus TAR estimate of ZEV plus NRC 'high most likely' adjustment in *2016 PP High*. The gross premiums in COMET are obtained directly from the COMET model account for ZEV and some NRC adjustments. The premium for trucks does not account for ZEV.

There are important caveats to these findings. First, COMET is based on EPA data in the TAR (2016) while the other 2016 perspectives are based on NHTSA data. This suggests that one must be careful when interpreting the differences in sales impacts between the respective lines in Figures 9.8a and 9.8b. Second, the COMET results allow for manufacturers to comply with ZEV using both cars and trucks, whereas the other 2016 perspectives presume there will be no ZEV trucks prior to 2025.

9.72 Allocation of ZEV Costs Across Prices of Both Cars and Trucks

One of the key simplifying assumptions of our TCO analysis is that manufacturers comply with the ZEV mandate by adding technology to cars alone and pass those costs on to car buyers with a price premium. While it might be reasonable to assume that ZEV technology will only be applied to cars prior to 2025, the assumption that the costs will only be passed on to car buyers is questionable. A more likely outcome is for manufacturers to allocate the ZEV compliance costs across all trucks as well as cars. Allocating the ZEV costs across cars and trucks lowers the price premium on cars and increases the price premium on trucks. This should reduce the negative sales impacts on cars and increase the negative sales impacts on trucks.

We illustrate this effect by assuming that manufacturers satisfy the ZEV mandate with only cars, but allocate those costs equally over cars and trucks. This is done using the simulation approach mentioned above, and the results are presented in Figures 9.9a and 9.9b for cars and trucks, respectively. As expected, allocating the costs of complying with the ZEV regulation between cars and trucks reduces the negative impact on cars while increasing the negative impacts on trucks, relative to the scenarios where the costs are applied only to prices of cars.

9.8 Modeling Comparisons, Unresolved Issues, and Future Research

We conclude by highlighting some intriguing differences between the REMI and TCO models and some unresolved issues, including promising topics for future research.

The TCO model focuses on impacts on new vehicle sales, and does not provide information about other economic indicators such as employment, GDP, and real disposable income. Nonetheless, there are some interesting similarities and differences between the TCO and REMI modeling exercises.

The two models are similar in that they both treat the vehicle price premium and fuel savings as main effects. The results of both modeling systems are also influenced by the trajectory of oil and gasoline prices: when fuel prices are low, the TCO model dampens consumer interest in fuel-efficient vehicles, and the automobile industry is more susceptible to a decline in new vehicle sales due to regulation; REMI also dampens the size of the fuel-savings effect when fuel prices are low, and thus lower fuel prices attenuate the macroeconomic benefits of the regulations.

There are also important differences. The TCO model does not have an equivalent of the supply chain innovation effect that is important in REMI, and, consequently, offsets at least half of the employment losses due to the vehicle price effect. REMI is designed with a larger price elasticity of demand (-1.65) than the TCO model (-1.0), so the adverse effects on motor vehicle demand are larger in REMI than in the TCO model. However, the price elasticity of demand in REMI applies only to retail consumers (as vehicle demand by government and businesses is assumed to be inelastic). Moreover, REMI has built-in adjustment mechanisms that attenuate the impacts of external price shocks, which means the adverse effects of a price increase attenuate over time (e.g., recall from Figure 8.7 how the employment losses from the vehicle price increase fall steadily from 2025-2035).

REMI does not incorporate any consumer demand for fuel economy, and thus the vehicle price effects operate through the gross price premium, as is typical of macroeconomic models. In the specialized TCO model, consumer demand for new vehicles operates through the net vehicle price premium, and thus fuel savings (directly and through resale value) have a substantial influence on demand for new vehicles. REMI is not equipped to model impacts from changes in the net vehicle price premium.

Figure 9.9a. Percentage Change in Car Sales by Model Year; 50-50 Allocation of ZEV Costs Between Cars and Trucks.

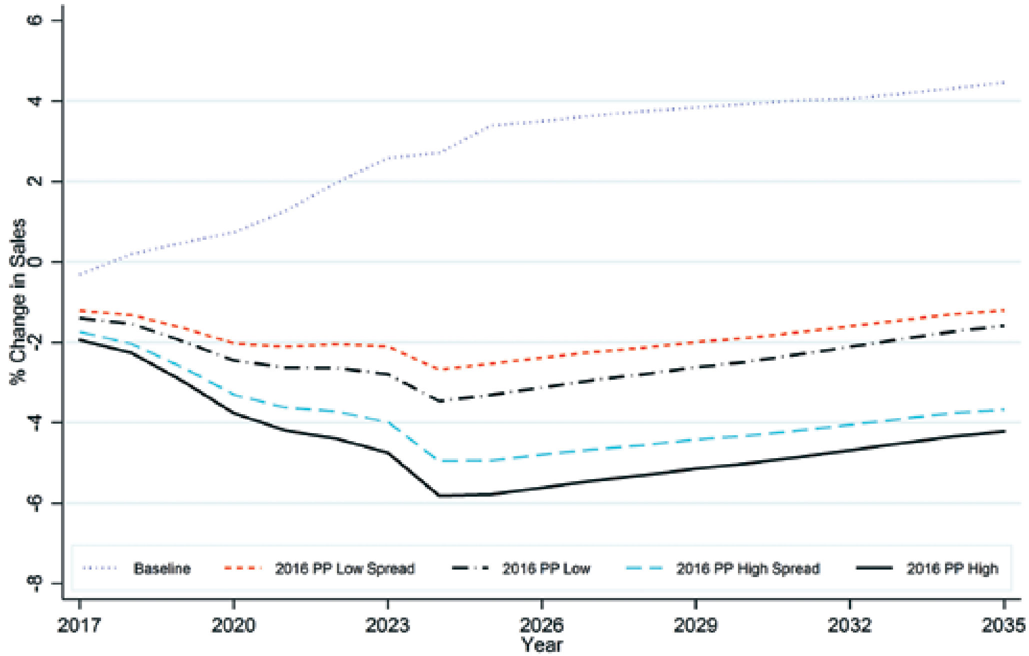
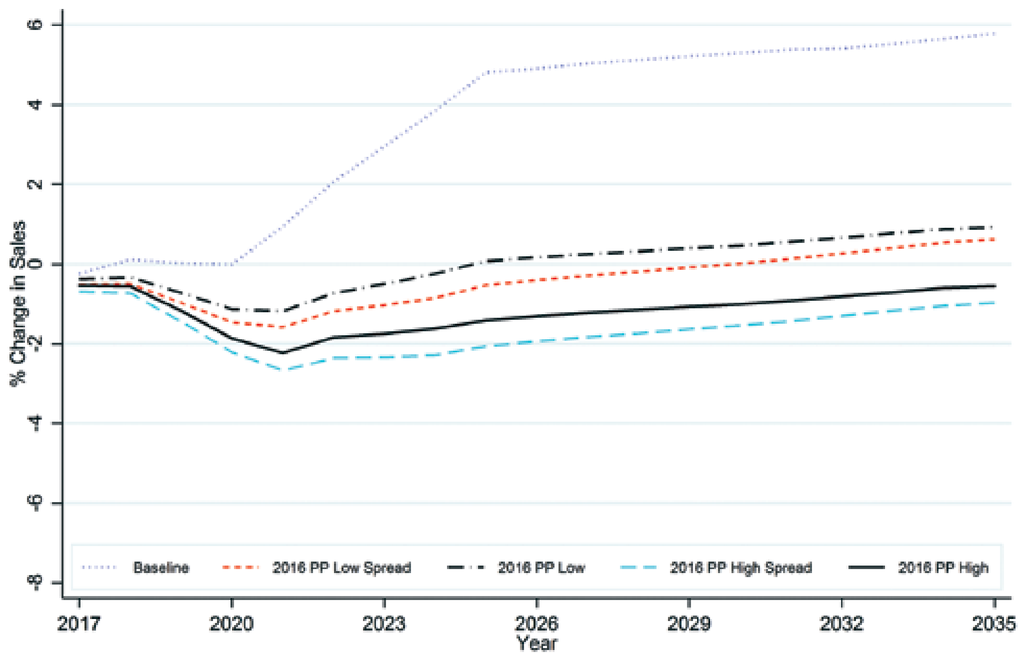


Figure 9.9b. Percentage Change in Truck Sales by Model Year; 50-50 Allocation of ZEV Costs Between Cars and Trucks.



Note: Reported in both Figures 9.9a and 9.9b is the percentage change in vehicle sales due to the regulatory programs based on our four perspectives. Baseline is based on NHTSA's 2012 data, and represents the 2012 perspective. The remaining lines represent the alternative 2016 perspective. Consumer valuation of fuel savings differs between the 2012 and 2016 perspectives: *Baseline* assumes that consumers value five years' worth of fuel savings, perceive resale value to equal to 35% of gross price premium, and perceive future fuel price equal to the AEO projections. The 2016 perspectives assume the consumer values three years of fuel savings, perceive future fuel price equal to fuel price at time of vehicle purchase, and perceive the incremental resale value to equal 35% of the gross premium. Gross price premium is equal to the NHTSA 2012 projections in the *baseline*; NHTSA 2012 plus DOE estimate of ZEV plus NRC 'low most likely' adjustment in the *Low* scenarios; and NHTSA 2012 plus TAR estimate of ZEV plus NRC 'high most likely' adjustment in *High* scenarios. We assume throughout that ZEV is satisfied only with cars. Lines labeled by the word *Spread* indicates that the ZEV premium is allocated 50-50 between cars and trucks; otherwise, the ZEV cost is allocated fully to cars.

Finally, the fuel savings in REMI are not attenuated by any consumer perceptions, undervaluation, or temporal preferences. The fuel savings for consumers in REMI exert their full effect when they are experienced in an actuarial and temporal sense. REMI does not adjust economic outcomes based on expectations.

10. QUALITATIVE POLICY ANALYSIS OF THE FEDERAL AND STATE REGULATORY PROGRAMS AND RELATED FISCAL POLICIES

Our macroeconomic analyses of the regulatory programs portray a future of some near-term decline in the health of the U.S. economy in exchange for even greater long-term improvements in the U.S. economy. Use of the 2016 inputs instead of the 2012 inputs accentuates the near-term negatives and dampens the long-term positives. Nonetheless, even with the 2016 inputs, the macroeconomic analyses do not provide any analytic basis for rescission of the federal programs. Under both sets of inputs, the long-term outcomes for the U.S. economy appear favorable.

In this section, we explore regulatory reforms that might preserve most or all of the long-term gains from the federal and California programs while limiting the near-term losses in the U.S. economy. We begin with the federal programs, and then examine the California ZEV program, as we express more fundamental concerns about the latter. Since we provide only a qualitative analysis of the reforms here, each reform should be subjected to its own cost-benefit analysis before it is enacted, as would typically be required under presidential executive order requirements. We then consider the case for harmonization of the divergent federal and state fiscal policies toward AFVs, until it is time for fiscal policy makers to take a neutral posture toward AFVs and the internal combustion engine. We conclude with the consideration of higher gasoline taxes or a national carbon tax.

10.1 Reform of the Federal Programs

Here we examine possible reforms of the federal programs (NHTSA 2012a; EPA 2012a). We do not analyze the California GHG program separately, since it seems to make sense to treat compliance with the federal programs as adequate demonstration of compliance with the California GHG program. In the long run (post-2025), this issue may need to be revisited.

10.11 Stretch out the Federal Compliance Schedule

As currently designed, the stringency of the CAFE and EPA requirements ramp up significantly from model years 2022-2025, especially for light trucks. The consumer payback from those ramp-ups is unlikely to be attractive (in part, due to relatively low fuel prices that were not apparent when the schedule was designed), suggesting that adverse impacts on new vehicle sales are plausible. The TAR (2016) reports payback periods of 5 to 6 ½ years for the 2022-2025 federal standards using AEO2015 fuel prices and a 3% discount rate.

One option would be to retain the current CAFE and GHG targets, but stretch out those ramp-ups from 2025 to 2030 or 2035. The stretch out would allow additional time for the cost of fuel-saving technologies to decline, as NRC (2015a; 2015b) predicts will occur, and for fuel prices to rise, as EIA projects will occur from 2025-2030 and thereafter.

A disadvantage of the scheduling extension is that it will slow the rate of decline in gasoline consumption and GHG emissions from new vehicles compared to the current schedule. To offset this disadvantage, an equivalent or greater magnitude of benefit is obtainable by enacting policies that accelerate the rate of retirement of older vehicles from the light-duty fleet. If "cash-for-clunkers" programs are the policy instrument of choice, they need to be designed carefully in order to ensure reductions in gasoline consumption and GHG emissions (see Appendix II). Legislative action would likely be necessary to accelerate the retirement of older vehicles from the fleet. A corollary advantage of this approach is that it balances the focus on GHG emissions from new vs. old vehicles, as virtually all of the current policy focus is on new vehicles.

10.12 Automatic Reform Triggers

Another reform option is to include an automatic reform trigger based on compliance cost: if the cost of CAFE compliance is shown to exceed a certain level, then the regulatory compliance schedule would be stretched out, or noncompliance penalties would be reduced, or manufacturers would be given the option of providing funds for public education about AFVs. Automatic reform triggers are commonly used in cap-and-trade programs and in state renewable portfolio standards (i.e., alternative compliance payments).

Designing the reform trigger around compliance costs would be difficult because cost information is proprietary and cost varies across manufacturers. The average price of credits in the trading programs could be used to design a reform trigger, since the price of compliance credits will be influenced by the marginal cost of compliance. But, the price of credit trades is not currently disclosed publicly. Public disclosure of the transaction prices for credits might be an improvement in its own right, as we discuss below.

It is questionable whether high-volume automakers will use credit trading as a primary compliance strategy, since it runs a risk of triggering shareholder protests and harm to a company's public image. Moreover, regulatory agencies have a known tendency to devalue accumulated credits (e.g., see EPA's May 2010 decision to restrict credits earned in the 2009-2011 optional GHG credit program in EPA 2016c), so it would be quite risky for a high-volume vehicle manufacturer to rely on accumulated or purchased credits as a primary compliance strategy. Thus, the price of credits may not be a reliable source of information about compliance costs.

A more limited version of the reform trigger, which focuses on consumer payback, could link the pace of the regulatory ramp-up to EIA forecasts of fuel prices for model years 2022-2025. EIA makes annual adjustments to long-term fuel-price forecasts based on the best available information about world oil markets and other factors that impact fuel prices in the U.S. The rationale for focusing on fuel price is that it strongly influences consumer payback, as we demonstrated in Appendix I.

A complication with the fuel-price trigger is how to give vehicle manufacturers enough lead-time to adjust their product designs and volumes. If EIA lowers fuel-price forecasts in 2022, it is too late for automakers to adjust their products for model year 2022. A better approach would be for EPA and NHTSA, in the midterm review process, to commit to a planned linkage between EIA fuel forecasts and the stringency of the performance standards four years later. Thus, EIA's 2018 forecast would influence the final standard for model year 2022; the 2019 forecast would influence the final standard for model year 2023; and so forth through model year 2025.

Here we present an alternative illustration of how fuel-price forecasts might be linked to regulatory requirements. If EIA's 2020 fuel-price forecasts for 2025 rise significantly above $4 per gallon, then the federal requirements for model years 2022-2025 could remain as currently scheduled, as that was the fuel-price forecast when the schedule was developed. If the 2020 fuel-price forecasts for 2025 are less than $3 per gallon, then the ramp-up could be slowed considerably, possibly stretched out to 2035. If the 2020 fuel-price forecasts for 2025 land between $3 and $4 per gallon, then a stretch-out to 2030 might be appropriate.

EPA and NHTSA should consider carefully the merits of an automatic cost or fuel-price trigger. It might even be possible to change the penalty for noncompliance so that the penalty is low (high) when the cost of compliance is high (low) or when the projected fuel price is low (high). If the fuel-price trigger is preferred, it can be discrete or continuous in nature: a continuous approach would remove rigidities near a fuel-price cut-point while a discrete approach would be easier to explain to policy makers and the public. From a legal perspective, some reform triggers could be implemented with executive power; others would require legislative changes by the Congress.

10.13 Off-Cycle Measures

Compliance is currently measured by laboratory (dynamometer) tests that focus on engine operations and air emissions (Roland 2009). However, there are many valid ways for vehicle manufacturers to enhance vehicle fuel economy and reduce GHG emissions that are not measured in the specified laboratory compliance tests. Examples include better air conditioners, active grille shutters to modify airflow and improve aerodynamics, vehicle stop/start systems, electric heat pumps, solar panels, high-efficiency external lighting, solar reflective glass/glazing, solar reflective paint, active seat ventilation, and active transmission warm-up (Nelson 2013b).

EPA and NHTSA should develop a more systematic, consistent, and timely approach to off-cycle measures that automakers can use to reduce vehicle fuel consumption and GHG emissions.

Under current law, NHTSA is apparently not permitted to consider some off-cycle measures (e.g., air conditioners) under the CAFE program while EPA is permitted to consider them. In the midterm review, NHTSA and DOT could recommend legislative language to permit systematic, consistent, and timely use of off-cycle measures by both NHTSA and DOT. Such legislation might also authorize updating test procedures to represent current driving styles and road conditions.

The current EPA process has permitted some off-cycle measures (EPA 2015). EPA has a predetermined list of permissible off-cycle measures, but the list is limited and is associated with conservative (i.e., low) credit values. Measures that are not on EPA's list—or measures that deserve values larger than EPA's conservative default values—must be validated in 5-cycle testing that includes high speeds, hard acceleration, and cold temperatures. From 2012-2015, only one vehicle manufacturer had received off-cycle testing credits based on 5-cycle testing (EPA 2016c). Alternative methodologies are permitted if manufacturers believe 5-cycle testing is not appropriate, but the multiple criteria applied to alternative methodologies are perceived as formidable. In only a few cases, alternative methodologies have resulted in the granting of off-cycle credits (EPA 2016c). The pace of decision making under the current program has been quite variable (Auto Alliance and Global Automakers 2016).

EPA and NHTSA should work together annually to update a comprehensive list of permissible off-cycle measures, each with a best-estimate value (rather than a low conservative value). Manufacturers and the public could be offered an opportunity to participate in the creation and validation of the annual list of off-cycle measures and credit values. Manufacturers should also be permitted to propose measures—or compliance credit values—based on alternative methodologies that are evidence-based and have been approved by an expert third-party review process. Those proposals should have a presumption of validity in a public comment and agency deliberative process. This more flexible approach to off-cycle measures, implemented jointly by NHTSA and EPA, might stimulate innovation in the industry and foster more cost-effective compliance with federal regulatory requirements.

10.14 Credit Trading: Harmonize and Modernize

As the federal performance standards become more stringent, the workability of the credit-trading programs may take on more significance. There are inconsistencies in the design of the credit trading programs at NHTSA and EPA that have no apparent rationale. They should be harmonized because each inconsistency reduces the potential cost-effectiveness of the two programs, since vehicle manufacturers must comply with both programs (Leard and McConnell 2015).

Here are some illustrations of the inconsistencies: the banking periods for credits are not aligned in the EPA and NHTSA programs; NHTSA places restrictions on trading between the light-truck and passenger-car fleets while EPA does not place such restrictions; and NHTSA has a separate standard for imported and domestic car fleets whereas EPA has one program for a manufacturer's entire car fleet. Harmonization to the more flexible approach can improve cost-effectiveness of the program, without compromising any gasoline savings or GHG benefits.

The credit-trading programs should also be modernized to reflect best practices. The prices of trades are not disclosed publicly, which weakens the ability of the marketplace to find the most cost-effective responses to the federal standards. A good case can also be made that the two credit-trading programs should be merged into one program (Leard and McConnell 2015).

10.15 Compliance Incentives for AFVs: Harmonize and Update

The compliance multipliers EPA offers to manufacturers for the sale of AFVs such as PEVs and FCVs are currently set to expire at the end of model year 2021. There may not be sufficient notice to eliminate them now, as the regulated companies have anticipated them in their product plans. However, if the multipliers are to be extended beyond model year 2021, an analysis should be conducted to justify them, as no such analysis was ever provided. They reduce the GHG and gasoline-savings benefits of the federal programs from 2017-2021 (Jenn, Azevedo, and Michalek 2016).

The schedule for the compliance multipliers may also need to be reconsidered and updated, in light of new data from the marketplace. The EPA multipliers were added when the Obama administration was working to put 1 million PEVs on the road by 2015 (Rascoe and Seetharaman 2013). As a result, the compliance incentives for PEVs that start in model year 2017 are phased down, and disappear in model year 2022, since it was expected that the viability of PEV commercialization would have been demonstrated before 2022.

It has proven much more difficult to commercialize PEVs in the U.S. than regulators or industry envisioned (NRC 2015b; Graham et al. 2014; Shepardson 2016). As such, instead of expiring in 2022, the incentives for PEVs in the federal program might need to be extended until 2025, if the federal government is serious about a national transportation electrification strategy. The federal decision on this issue should be made in collaboration with CARB, as it refines the ZEV program. A joint analysis from CARB, EPA, and NHTSA should be prepared to determine whether the compliance incentives should be retained and extended.

If the compliance incentives are extended, the crediting preference for BEVs over PHEVs should be reconsidered. In 2012, EPA did not supply an analysis to support the preference for BEVs over PHEVs. Evidence suggests that PHEVs can be more cost effective than BEVs, depending on how they are designed and used (Michalek et al. 2011). Moreover, mainstream consumer interest in PHEVs may be easier to muster, largely because their driving range is typically comparable in length to a gasoline vehicle (Graham et al. 2014). Furthermore, PHEVs may serve as a practical bridge to BEVs, much like HEVs have served as a useful bridge to PEVs (Axsen and Kurani 2008; Colias 2015). In some countries in the world, public policies are more favorable to PHEVs (relative to BEVs) than they are in the U.S. (IEA 2016).

Insofar as compliance incentives are to be used to stimulate commercialization of new technology, it may be useful to focus compliance incentives on segments of the automotive market where PEV penetration is weakest or non-existent. A consumer today has no difficulty finding a PEV offered as a small car, but PEV penetration among crossovers and light trucks is much more limited. Given that consumers are expressing growing interest in crossovers and light trucks, it might be useful to focus PEV compliance incentives in those segments (IFC 2015).

Finally, if the multipliers are to play their intended role in the compliance decisions of vehicle manufacturers, the same multipliers should be present in both federal programs. Offering compliance multipliers at one agency but not the other does not offer an incentive for PEV commercialization or compliance flexibility for manufacturers.

10.16 Provide Better Fuel-Economy Information to Consumers

If the concern of regulators is that some consumers undervalue the private benefits of fuel economy (i.e., savings in gasoline expenses), the most straightforward solution is to provide information to consumers to combat the undervaluation. There is plenty of evidence that many consumers do not make present-value calculations of fuel-saving technologies (Turrentine and Kurani 2007) and that many consumers misinterpret the information made available by EPA on fuel-economy labels (Larrick and Soll 2008).

Several years ago, EPA took a step in this direction by modifying the fuel-economy label on new vehicles to emphasize how much fuel and money will be saved over a five-year period, if a consumer chooses a vehicle with an above-average EPA rating for fuel economy. Although EPA conducted some focus groups to inform this change in labeling, the new label was not subject to a large-scale randomized trial to determine whether the revised label made any difference to consumers. The only randomized trial in the literature on this subject found no evidence that the EPA's revised label changed consumer intention to purchase an HEV, a PHEV, or a BEV (Dumortier et al. 2015). Instead, that trial found that greater use of total cost-of-ownership information impacts the stated purchasing intentions of some new car buyers. On the other hand, two recent experiments with fuel-saving information (i.e., annual and vehicle-lifetime fuel costs tailored to the consumer's personal situation) did not find a significant impact on the purchase of fuel-efficient vehicles (Allcott and Knittel 2017).

A priority for the federal government is a serious commitment to behavioral research that clarifies which consumers undervalue fuel economy and how information programs should be designed to meet their needs. Targeting an information solution at the proper subgroup of consumers is generally a superior strategy to raising CAFE standards for all new vehicles, since some consumers may not be undervaluing fuel economy and would prefer not to pay for the more expensive mandated technologies (Allcott and Greenstone 2012; Allcott, Mullainathan, and Taubinsky 2014).

10.2 Reform of the California ZEV Program

The ZEV regulation was not incorporated into the 2012 Joint National Program designed by the Obama administration from 2009-2012. We have not been able to find any explicit justification for the exclusion of ZEV regulation from the design of the JNP. The simultaneous presence of two federal programs and the California ZEV program creates the potential for regulatory interaction and unintended consequences (Goulder and Stavins 2012; Roth 2014).

Both EPA and CARB are taking the position that they lack the legal authority to subject the ZEV program to a national cost-benefit or cost-effectiveness test (EPA 2013). CARB's 2011 RIA was undertaken as if the federal programs for model years 2017-2025 did not exist. In addition, the 2012 EPA and NHTSA RIAs were conducted as if the ZEV program did not exist. EPA does not examine the cost-benefit case for the ZEV regulation during waiver requests under the Clean Air Act (as it defers to California's determinations) and EPA does not review the decisions of other states to join the ZEV program (EPA 2013).

Proponents of the 2012 ZEV regulation can rightly argue that EPA and NHTSA did not finalize their 2017-2025 standards until nearly a year after CARB approved its ZEV standards for model years 2018-2025, so CARB could not possibly have incorporated the final 2017-2025 federal standards into its baseline. However, on May 21, 2010, President Obama issued a "Presidential Memorandum Regarding Fuel Efficiency Standards" that directed EPA and NHTSA to develop stricter fuel economy and GHG standards for model years 2017-2025. He also called for those stricter standards to be "harmonized" with "applicable" state standards.

Since CARB knew where the federal government was headed, they could have performed some scenario or sensitivity analyses showing how the case for the 2018-2025 ZEV standards might be impacted by stricter federal CAFE and GHG standards. Such analyses may have suggested that some delay in the CARB standards would have been desirable from a harmonization perspective. More importantly, the proposed federal standards were announced for public comment by the White House on July 29, 2011, a full five months before the ZEV standards were finalized by CARB. The White House announcement refers explicitly to federal performance standards equivalent to 54.5 miles per gallon in model year 2025. From an analytical perspective, CARB had ample time to incorporate the federal proposal into its baseline, as the CARB analysis was not released until December 2011.

The lack of coordination is an invitation to perverse consequences since the federal and ZEV regulations have similar objectives and cover the same industry. In the course of studying the complex provisions of the ZEV regulation and the federal programs, we uncovered some potentially important interaction issues that are begging for careful analysis, as we have discussed in several places in this report.

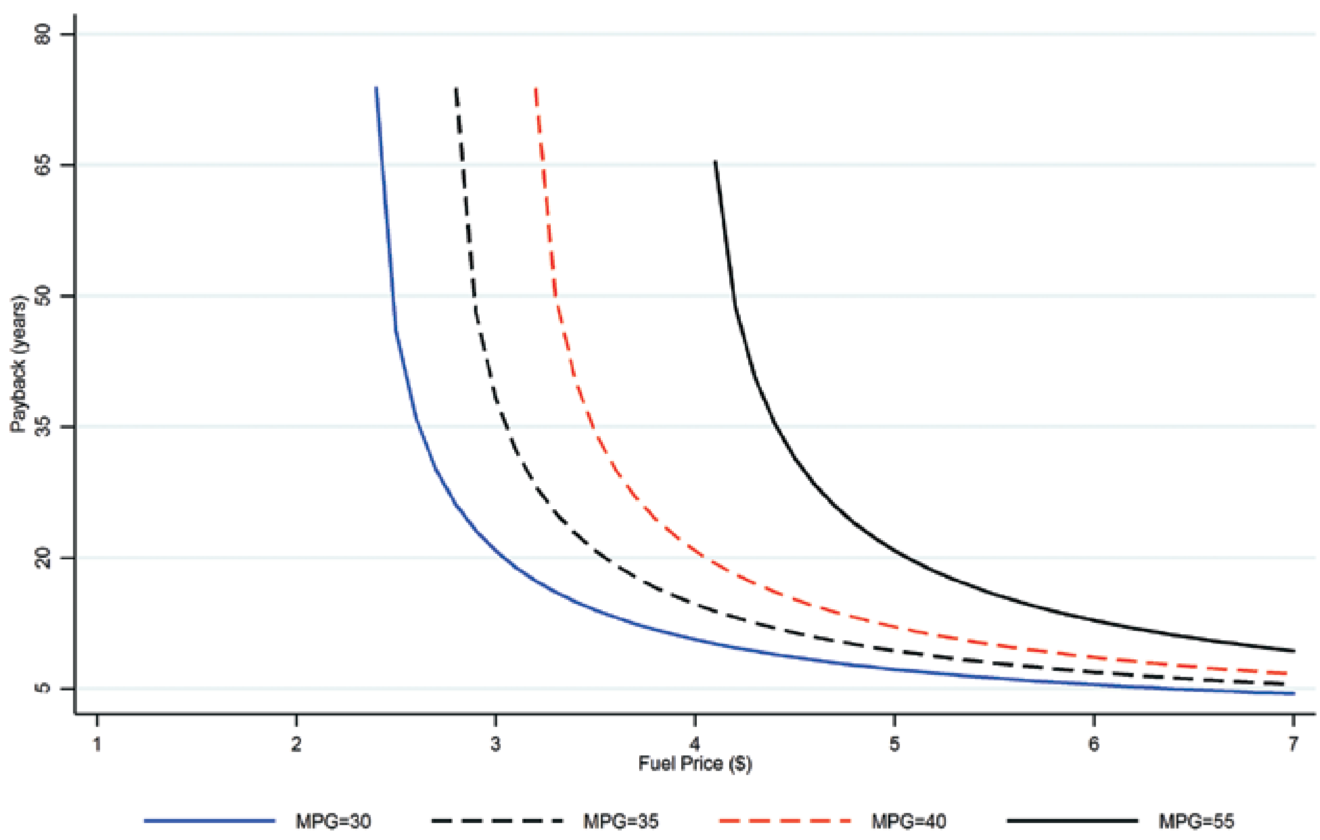
10.21 PEVs Have a Longer Consumer Payback Period When the Federal Programs Serve as the Baseline

We prepared a consumer payback analysis for a BEV at an interest rate of 5% (CARB's assumption) with alternative assumptions about fuel price and fuel economy of a gasoline-powered car. Based on industry experience and recent survey evidence, a consumer payback period longer than three years is considered unattractive by the typical retail car purchaser (Small 2010; Greene, Evans, and Hiestand 2013; CAR 2011; NRC 2015a).

The results in Figure 10.1 show that the attractiveness of the consumer payback from a BEV purchase declines as gasoline-powered cars become more fuel-efficient. This conclusion is evident in the upward and rightward shift of the payback curves as the average fuel economy of gasoline vehicles increases from 30 MPG to 55 MPG in Figure 10.1. In other words, for a given interest rate and fuel price, the consumer payback period for a BEV becomes longer as the average fuel economy of gasoline cars increase, all else equal. This insight suggests that the increased fuel economy mandated by the federal standards is likely to undermine the commercial success of BEVs, complicating implementation of the ZEV program and threatening a loss of new vehicle sales due to the ZEV requirements.

The fact that the ZEV payback periods extend beyond three years does not mean that, from a societal perspective, the ZEV regulation is inefficient. That kind of conclusion requires findings from a full cost-benefit analysis, including financial impacts beyond the third year of ownership as well as environmental impacts. The simple point made here is that vehicles produced under the ZEV standards will be more attractive to consumers without the 2017-2025 federal standards than with the 2017-2025 standards and thus there is a serious interaction that needs to be considered when analyzing consumer response.

Figure 10.1. Payback Analysis (in Years) for a BEV with a 100-Mile Range Compared to Four Gasoline Vehicles.



Note: Reported is the payback period (in years) required to recoup the incremental cost of buying a battery-electric vehicle (BEV) at an interest rate of 5% and under various assumptions about fuel price. The BEV is compared to a traditional gasoline powered vehicle that gets 30, 35, 40, and 55 MPG, respectively. We assume that the consumer drives 12,500 miles per year, that the BEV has a range of 100 miles on a full charge of 35 KWh, and that electricity costs $0.15/KWh. We assume that the price premium is $11,551 for each of the gasoline cars except for the car that achieves 55 MPG where we assume a price premium of $9,751. The difference in resale value between the BEV and traditional vehicle is assumed to be zero. The analysis assumes that all parameter values are constant over the life of the vehicle, which implies that fuel savings are constant across time.

10.22 The ZEV Regulation is Unlikely to Reduce GHG Emissions Due to the Corporate Averaging Provisions in the Federal Programs

CARB (2012b) has already acknowledged that the rationale for the ZEV program has shifted to GHG control as well as local air quality management. CARB argues that it is already apparent, based on the best available climate science, that California must achieve 40% penetration of ZEVs by 2030 and 100% penetration of ZEVs by 2050. Otherwise, the State's climate-policy goals will not be met (CARB 2011a; CARB 2016). For the ZEV regulation to make a meaningful contribution to GHG control, it needs to be coordinated with federal GHG regulation.

Manufacturer compliance with the ZEV regulation moves each affected company closer to meeting federal CAFE and GHG targets. That means each affected manufacturer can adjust their product designs for gasoline vehicles, invest fewer resources in fuel economy and GHG control, and allocate more resources to other fuel-expending attributes such as performance, comfort, and trunk space (NRC 2015b, 354). Thus, although each ZEV sold will emit less pollution than the average gasoline vehicle, the weighted average rate of GHG emissions from all new vehicles is not likely to be affected by the presence of the ZEV regulation (NRC 2015b; Jenn, Azevedo, and Michalek 2016; ICCT 2012).

This interaction with federal programs has already been acknowledged by CARB, though in a somewhat different context: "fleet average requirements ensure that air quality benefits do not suffer as a result of an automaker producing fewer ZEVs" (CARB 2014, 17). This comment was made in reference to the positioning of the ZEV program within California's Advanced Clean Car Program, which sets fleet average emission standards commensurate with EPA standards, and CARB's proposed modifications to the ZEV program that would relax some requirements for intermediate-volume manufacturers. As long as the federal program is binding on a vehicle manufacturer, each ZEV produced for California will permit the manufacturer to produce one or more less fuel-efficient cars elsewhere in the country.

In a similar vein, CARB's 2006 GHG standards (pursuant to AB 1493, 2002) for new passenger vehicles have been shown to have only limited environmental benefits when they are implemented in the context of a national EPA GHG performance standard that contains fleet-wide averaging provisions (Goulder, Jacobsen, and van Benthem 2012). Fortunately, the CARB GHG standards were carefully integrated into the One National Program, so the environmental benefits of CARB's GHG standards are captured by the federal programs, with no incremental cost imposed on vehicle manufacturers or consumers. No such integration was undertaken for the ZEV program.

Notice that this line of argument is different from the commonly-made claim that PEVs do not reduce pollution because a PEV draws its electricity from an electric power plant that emits pollution. Lifecycle comparisons of PEVs that count pollution from the power plant as well as from the tailpipe suggest that they have significant GHG advantages over gasoline vehicles, as long as the carbon-intensity of power production is sufficiently low (NRC 2015b; Tessum, Hill, and Marshall 2014). The ZEV states—especially California—depend more on natural gas and renewables than coal as a source of energy for electric power production, which helps explain why the lifecycle analysis of a PEV is generally favorable in ZEV states. The problem with the ZEV regulation is not the induced emissions at the powerplant but the lack of coordination with the federal programs.

10.23 The ZEV Regulation May Not Reduce Local Smog Levels in Polluted California Cities Due to Unexplored Regulatory Interactions

Because GHGs are a global pollutant, it does not matter whether the emissions occur in California or in another state or country. The impact on climate change is the same, regardless of emission location. Pollutants such as smog and soot need to be analyzed differently because they have localized effects where human exposure is elevated.

In fact, the original rationale for enactment of the ZEV program in 1990 was to control local smog in the congested cities of ZEV states. The Los Angeles region and San Joaquin Valley are both classified as "extreme nonattainment areas" by EPA due to excessive smog levels (CARB 2012a). The volume of PEVs required in California to achieve attainment with health-based air quality standards may be greater than the volume of PEVs required to achieve the State's GHG-control goals (E3 2014). But, the ZEV regulation does not necessarily affect smog levels due to unanalyzed interactions of the ZEV program with other CARB and EPA regulatory programs.

CARB and EPA standards for controlling smog- and soot-forming pollutants from new vehicles have become so stringent that the environmental advantages of a ZEV are not nearly as large today as they were when the ZEV program was authorized by Congress in 1990 (EPA 2014; IFC 2015). Moreover, some degree of local pollution will also occur at the electric power plant when the ZEV is plugged into the electrical grid. For example, nitrogen dioxide (NO2) emissions from a power plant fueled by natural gas will contribute to urban smog in many cities, depending on the chemistry of the downwind ambient environment. The net effect of PEVs on local pollution will depend on how the electricity sector is regulated for emissions (Holland et al. 2016; Linn and McConnell 2013).

The corporate averaging provisions in the CARB and EPA tailpipe standards for smog- and soot-forming pollutants also need to be considered. When a ZEV is produced, the manufacturer can count that vehicle's zero NO2 emissions toward their compliance with CARB's 2012 tailpipe standards and EPA's 2014 tailpipe standards for NO2. The manufacturer is then free to sell other vehicles that have somewhat larger emissions of NO2. Even if the NO2 emissions averted by a PEV are at a different location than the NO2 emissions induced by corporate averaging, there may not be any net improvement in public health due to the pollution transfer. Detailed air quality modeling, coupled with dose-response modeling of health impacts in each affected locality, is required to determine whether pollution transfers cause a net gain for public health.

10.24 The Technology-Innovation Argument for the ZEV Regulation Should Be Analyzed in the Context of Alternative Approaches to Spurring Innovation

Some proponents of the ZEV regulation defend it as a policy tool to stimulate the development and commercialization of new technologies that will enable stricter federal standards after model year 2025. Without the ZEV regulation, automakers are likely to focus R&D on refinements to the internal combustion engine, since those refinements are more cost effective than a PEV or FCV (NRC 2015a). Automakers and their suppliers might delay development and commercialization of PEVs and FCVs for many years. According to this view, the ZEV regulation has long-term environmental value that is complementary to the federal programs.

There is also an international variant of the technology-innovation argument. ZEV technologies demonstrated in California will make it easier for other countries, such as China and India, to control GHG emissions in the decades ahead (Lippert 2015; Fischer, Harrington, and Parry 2007). Given that global imperative, ZEV regulation may be seen as necessary or useful to help prepare automakers, suppliers, dealers, motorists, utilities, and communities for an accelerated transition to ZEVs.

Although the technological-innovation argument has merit, it needs to be evaluated in the context of plausible R&D alternatives to the ZEV regulation. The U.S. Department of Energy (DOE) has a significant research, development, and demonstration program aimed at stimulating the commercialization of clean engines and fuels, including ZEV-like technologies (Roth 2014). The DOE program could be expanded to include community demonstrations of PEVs and FCVs in several regions of the country. Norway and the Netherlands have used incentive-based policies to accomplish a faster rate of PEV penetration than California has achieved with the ZEV standards (IEA 2016; Figenbaum and Kolbenstvedt 2015). Moreover, since other countries are already demonstrating PEV technologies (IEA 2016), California is not making a unique international contribution by forcing commercialization of PEVs. Thus, it does not appear to be necessary to implement a ZEV regulation in order to provide PEVs a viable opportunity for significant commercialization.

10.3 Reconsidering the EPA Waiver

Insofar as the ZEV program does not provide significant environmental benefits or has costs greater than benefits, stemming in part from interaction with federal regulatory programs and consideration of alternative policies, then EPA should use its waiver authority to work with CARB to improve and coordinate the ZEV program. Since removal of ZEV's waiver would be unprecedented, it would likely face years of complex litigation with uncertain outcomes. Thus, a cooperative approach between EPA and CARB, using the waiver as the context, may prove to be a productive approach.

Historically, when granting a ZEV waiver, EPA has not even considered whether the incremental air quality benefits of the ZEV program justify the costs of the ZEV program (EPA 2013, 2155). CARB has prepared a cost-benefit analysis of the ZEV regulation from California's perspective (CARB 2011a), but a demonstration that the ZEV program is in California's interest does not necessarily mean that the ZEV program is in the interest of the U.S.

Consider a recent study that compared the costs and benefits of a PEV from California's perspective. The costs included incremental costs of producing the vehicle, charging infrastructure costs, and the costs of delivered electricity. The benefits included the federal tax credit (up to $7,500 per vehicle) for the consumer, gasoline savings, and reduced greenhouse gas emissions. They found that the benefits to California of each PEV were about $20,000 per vehicle, which was almost $5,000 greater than the estimated costs per vehicle. The authors note that the federal tax credit is important to the favorable benefit-cost result, though the importance of the credit declines as the projected cost of producing a PEV declines due to innovation in battery technology (Cutter 2015; 2016; IFC 2015).

Evaluation of the same PEV from the U.S. perspective would be quite different. The federal tax credit would represent a transfer and thus would be excluded from the cost benefit analysis. The gasoline savings and environmental benefits would be much smaller (and possibly close to zero) due to the corporate averaging provisions in the EPA GHG and smog/soot control programs. Moreover, the extra costs of the PEV are unlikely to be charged to the PEV buyer in California because the large price premium would make it difficult for manufacturers and dealers to sell the vehicle. If the extra cost is instead spread among all U.S. vehicle purchasers, as CARB and EPA have suggested (2013), then more than a majority of the price burden would be felt outside of California and the 10 ZEV states. This conclusion does not even consider the distribution of the economic development impacts: California gains employment at PEV start-up and recharging companies while gasoline engine producers in the South and Midwest lose production volume to battery-back producers.

The federal government should take a careful look at whether the costs and benefits of the ZEV program differ from a California vs. national perspective. An independent body such as the Congressional Budget Office or the National Research Council should be commissioned to undertake the evaluation. A similar comparison should be done for the 10 ZEV states vs. the nation as a whole, since EPA does not review the decisions of other states to adopt the California standards. This matter has some urgency because both EPA and CARB are taking the legal position that neither has the authority to evaluate the costs and benefits of the ZEV program from a national perspective (EPA 2013). A more definitive solution would be for the Congress to amend the Clean Air Act and require ZEV waiver decisions to be supported by a national cost-benefit analysis.

10.4 National ZEV Program

If it is determined that continuation of a ZEV regulation is appropriate, then the inquiry should shift to whether the mandate should apply only to California and the other nine ZEV states or whether a national ZEV regulation under EPA or NHTSA authority would be preferable. A uniform national ZEV program could provide equivalent or greater GHG control while providing more compliance flexibility to vehicle manufacturers.

Under the current ZEV mandate, vehicle manufacturers earn no compliance credit for ZEVs sold outside of California and the other nine ZEV states (except for bonus EPA credits that expire after model year 2021). In a national ZEV scheme, a ZEV sale in Atlanta would have equal value to a ZEV sale in San Francisco. If a national ZEV program is considered, the precise levels of stringency need to be determined based on careful technology assessments, environmental modeling, and cost-benefit analysis. If a long-term commitment is made to a national ZEV regulation, then continuation of the NHTSA-CAFE, EPA-GHG, and CARB-GHG performance standards may not be necessary. A simplification of the number of regulatory programs and agencies would be a step in the right direction.

When considering a national ZEV program (or an extension of the California ZEV program), there should also be some analysis of the federal incentives for PEVs and FCVs that are already in place (e.g., the $7,500 federal income tax credit for qualified PEVs, the larger federal credit for FCVs, and the compliance incentives for BEVs, PHEVs, and FCVs in the 2012 EPA GHG rule). The array of state-level incentives for ZEVs also needs to be considered. The interaction between federal and state incentives for ZEVs and the state and federal regulatory requirements have not yet been analyzed by EPA, NHTSA, or CARB, despite repeated calls for such analyses (CBO 2012; McConnell and Turrentine 2010; Linn and McConnell 2013).

A possible argument against a national ZEV program is that the environmental damages from use of gasoline and electricity are not uniform across the country. One study found that the average rate of environmental damage from electricity use is much lower in California (e.g., where coal is rarely used in power production) than in the nation as a whole (Holland et al. 2016). Moreover, gasoline use in California is more environmentally damaging than it is in the rest of the country, in part because the seven counties in the country with the most severe particle pollution are all in California (EPA 2013). A complete version of this analysis needs to project the pathway for gasoline and electricity prices in each of the 50 states, and determine how much interstate difference there is in the financial case for ZEVs as consumers may be strongly influenced by the financial considerations. If the net benefits of PEVs are positive in all 50 states, the policy direction should be different than if the net benefits are highly variable across states.

10.5 Reforms of the ZEV Program

If it is determined that a California ZEV regulation should be pursued instead of a national ZEV program, there are some reforms of the ZEV regulation that are worthy of consideration. We mention a variety of reforms here, recognizing that the State of California should prepare a careful supporting analysis before adopting any of them. Although we focus on California, most of the reforms are relevant to all 10 ZEV states.

10.51 Stretch out the Schedule for ZEV Requirements

One option would be to retain the current ZEV requirements but stretch out those ramp-ups from 2025 to 2030 or 2035. The stretch out would allow additional time for the cost of PEVs and FCVs to decline, as NRC (2015a; 2015b) predicts will occur, and for fuel prices to rise, as EIA projects will occur from 2025-2030 and thereafter. Communities in ZEV states (especially those located outside of California) also need more time to become ready for rapid market penetration of PEVs and FCVs. CARB has taken similar steps in the past, when it was apparent that market conditions could not support rapid commercialization of PEVs. EPA has stated, in the context of ZEV waiver decisions, that cost of compliance is a lawful consideration if the cost is related to the appropriate timing/schedule of the standards (EPA 2013, 2134). EPA views that type of cost consideration different than a cost-benefit or cost-effectiveness analysis, which they defer to California (EPA 2013, 2134).

The argument made here is not for rescission of the ZEV regulation. Since lithium ion battery prices appear to be declining rapidly, any relaxation of the ZEV compliance schedule should be undertaken with care, since the compliance pressure on automakers and their suppliers may be contributing to innovations such as cost-effective improvements in battery design and production methods. Without some compliance pressure, cost reductions may slow down or come to a halt, though global demand for PEVs may sustain the incentive for innovation.

10.52 Extend the Travel and Regional-Pooling Provisions

The travel provision, which allows manufacturers to apply compliance credits earned for BEVs in one ZEV state to all other ZEV states, expires at the end of model year 2017. The elimination of the travel provision will essentially mean that manufacturers will be compelled to rapidly increase their production and sale of BEVs in each of the 10 states. However, as we explain below, many states—including some ZEV states—are not yet ready to accommodate electrification of their passenger vehicles. Thus, it may be prudent to extend the travel provision for several years until communities are prepared.

CARB's regional credit pooling arrangement is a useful innovation and would be even more useful in burden reduction if it were designed with fewer restrictions. For example, instead of requiring manufacturers to comply with ZEV requirements in each of the nine ZEV states, variable percentage requirements in the western and eastern regions could be based on the extent of regional progress in community readiness for PEVs and FCVs. The western region might have a more ambitious requirement than the eastern region until eastern states make progress on readiness.

Insofar as GHG control is the primary rationale for future ZEV requirements, more flexibility should be provided in the regional pooling arrangements, since it does not matter where GHG emissions occur. CARB currently does not permit over-compliance in California to be used by a manufacturer to compensate for shortfalls in the eastern or western regions. Counting California in the western region would add some more flexibility. Reducing the penalty for transferring credits across regions is also worthy of consideration. Some of the additional flexibility mentioned here can be provided by CARB; other forms of flexibility may require legislation.

10.53 Give PHEVs a Larger Role in the Future of the ZEV Program

PHEVs, even those with a short all-electric range, are a more promising and cost-effective strategy for GHG emissions control and oil savings than BEVs, at least in the near term (Michalek et al. 2011). Moreover, PHEVs may be a useful bridge to BEVs, like HEVs have helped pave the way to PEVs.

Over time, though, BEVs may compete more favorably with PHEVs, at least in some applications. PHEVs have an inherent long-term cost disadvantage because two powertrains are required rather than one (NRC 2015b). Indeed, the federal agencies, in the draft TAR (2016), are projecting that the cost of producing BEVs will fall faster than the cost of producing PHEVs, eventually creating a cost advantage for BEVs over PHEVs. It may take a long period of time for long-range BEVs to achieve that cost advantage, so PHEVs are promising in the years ahead (TAR 2016).

Supporting this reform is the depressed condition of the PEV market, where consumer demand for BEVs, with the possible exception of Tesla's products, is not approaching the supply mandated under the ZEV regulation (Shelton 2015). Manufacturers already report incurring losses on BEV sales, stemming from high production costs and price discounts offered to encourage their sale. In 2013, the Chrysler Group conceded publicly a loss of $10,000 on each sale of a new Fiat 500e (Woodyard 2013b).

The simplest approach would be to increase the number of credits awarded for PHEVs (classified as TZEVs under the ZEV program) or increase the fraction of PHEVs that large manufacturers can count toward compliance with ZEV requirements. An alternative reform is to reset ZEV regulatory requirements according to electricity miles over a vehicle's life, instead of according to production quotas by vehicle type. For example, when operating a BEV, a 25-mile reserve is typically required while a PHEV can use 100% of its electric range (given that the gasoline engine is available as a backup) (Bienenfeld 2016). GM cites data showing that, for the updated Volt (which has 53 miles of all-electric range), 90% of trips and 65% of vehicle miles of travel are in e-mode only (Mims 2016). BEVs are used 30% less than gasoline vehicles because of their range limitation (TAR 2016). Electricity miles may be a reasonable alternative to the current system, as it would credit vehicles based on their actual real-world performance (Nelson 2015). Our understanding is that additional data on this issue will be collected and considered in CARB's midterm review process.

More generally, California's policy preferences for BEVs over PHEVs should be reconsidered (Michalek et al. 2011; Peterson and Michalek 2013). The cash rebate in California for a BEV ($2,500) is larger than for a PHEV ($1,500). Other states tend to have a similar BEV preference. Internationally, the pattern is more complex, as some countries have adopted public policies that put the PHEV on a more even footing with the BEV (IEA 2016).

Until recently, California's HOV-lane access was designed to favor BEVs over PHEVs. An unlimited number of carpool lane stickers were made available to owners of BEVs or FCVs; only 40,000 (recently increased to 85,000) stickers were made available to PHEV owners (Berman 2012; CARB 2016). The stickers for PHEVs reached the limit, which discouraged sales of PHEVs. Recently, California changed its position and decided to allow an unlimited number of stickers for PHEVs as well as for BEVs (Kane 2016).

Since the U.S. market shares of BEVs and PHEVs were roughly 48% and 42% (of total PEVs), respectively, in 2016, one is tempted to conclude that the PHEV is not more attractive to consumers, even though it has a large advantage in driving range (Cobb 2017). However, as explained above, federal and state subsidy policies tend to be biased toward BEVs, and vehicle manufacturers have received a clear message that CARB and federal regulators prefer BEVs to PHEVs. Thus, the market competition between BEVs and PHEVs has not occurred on a level-playing field—a bias that should reconsidered. The experience in Norway is that PHEVs and BEVs appeal to different subsets of consumers: BEV owners are more likely to live in urban centers and own multiple vehicles; PHEV owners are more spread out geographically and are more likely to be single-vehicle households (Figenbaum and Kolbenstvedt 2016).

10.54 Enhance Community Readiness for PEVs

The success of the ZEV regulation can be enhanced by implementing measures that improve the readiness of communities for PEVs and FCVs (Clinton et al. 2015; Sierzchula et al. 2014; Graham et al. 2014; Lutsey et al. 2015). Currently, some states and cities are much better prepared for PEVs than other cities (Carley et al. 2013), however, better-prepared cities are not necessarily located in ZEV states (Clark-Sutton et al. 2016). Atlanta, Georgia, for example, has highly progressive PEV policies and one of the highest penetration rates of PEVs among U.S. cities, primarily due to sales of the Nissan Leaf, but Georgia is not a ZEV state (Ramsey 2014). A systematic analysis of PEV readiness in the 31 largest U.S. cities found no strong evidence that PEV-ready cities are more likely to be located in a ZEV state (Clark-Sutton et al. 2016).

Making home charging of PEVs convenient and inexpensive is key to community readiness. Utility data from California show that 74-80% of charging occurs at home (E3 2014). But some public charging stations are also required for optimal community readiness, especially where short-range BEVs dominate the PEV fleet.

Even the best prepared states and cities have a long road ahead to achieve a high degree of PEV readiness. One indicator of PEV readiness is availability of public charging stations. The rate of PEV sales in California (3%) is much higher than the national average (0.9%), in part reflecting the extensive efforts made in California to pave the way for PEVs (IEA 2016). A 2014 study presents different charging infrastructure scenarios in relation to California's PEV goal of having 1 million PEVs on the road by 2020. Under one scenario, 50,150 public charging outlets would be needed to accommodate expected growth in PEVs (Melaina and Helwig 2014). A different study in California estimated that, if the State meets its goal of having 1.5 million PEVs on the road by 2025, 230,000-410,000 PEV recharging sessions will be needed daily—an 18-fold increase over what was available in 2014 (E3 2014). As of September 2016, a total of 11,855 charging outlets were available for public use in California (California Energy Commission 2016; DOE 2017a). New England states are only beginning to work on readiness and, not surprisingly, PEV sales rates in New England are only slightly above the national average. Surveys show that car shoppers in the Northeast are much less aware of PEVs than car shoppers on the West coast (Kurani, Caperello, and Tyreehageman, 2016).

A wide range of federal, state, and local policies could be implemented in order to enhance community readiness for PEVs (NRC 2015b; Lutsey et al. 2015). Uniform standards, certification, and training throughout the industry are considered crucial to large-scale uptake of PEVs (S. Brown, Pyke, and Steenhof 2010). NRC (2015b) found that progress on each of these fronts is inadequate. If public subsidies are expanded, subsidies of batteries—and especially sustained R&D for enhanced batteries—are more cost-effective than subsidies of public charging stations (NRC 2015b; Roth 2014; Peterson and Michalek 2013).

Policy makers should use the NRC (2015b) report as a PEV blueprint about community readiness, and commission a similar report from NRC on readiness for FCVs.

10.55 Provide Support for FCVs as a Compliance Alternative

Critics have argued that the ZEV program is a "de facto industrial policy" that favors BEVs to the exclusion of other promising technological innovations (Knittel 2014). In theory, the ZEV regulation is structured as a performance standard; any technology that accomplishes zero emissions is acceptable. The most promising alternative to the PEV is the hydrogen FCV, but questions have been raised as to whether the State of California and other ZEV states are serious about FCVs.

The challenges for FCVs are much greater than for PEVs because very few hydrogen filling stations are available and the pace of infrastructure buildup is slow, even in California (Undercoffler 2016b). It appears that some automakers may choose to offer FCVs instead of PEVs to meet the ZEV mandate prior to 2025, but the infrastructure requirements for FCVs are significant (CARB 2016; Fleming 2015; Undercoffler 2016c). Some loans and grants for hydrogen stations are now available from the California Energy Commission, Toyota, and Honda (Undercoffler 2016b).

Toyota, Honda, Hyundai, GM, and some other automakers have worked diligently to bring down the costs of FCVs and demonstrate the technology to regulators and the public. In the fall of 2015, Toyota launched the Mirai sedan as a FCV for limited public use. The U.S. Congress has renewed the $8,000 federal income tax credit for purchases of a FCV. While CARB continues to encourage FCVs through its ZEV credit system and the FCV travel provision, the big missing ingredient is the development of a network of hydrogen refueling stations.

CARB pledged to play a leadership role in this area but the agency has acknowledged that progress has been slower than the agency expected (CARB 2016). Toyota's reluctant decision in late 2016 to launch a PEV program may be an implicit acknowledgement that the State of California is not a reliable partner on FCVs (McLain 2016b; McLain 2016c). Insofar as CARB is serious that the ZEV program is not simply a BEV mandate, accelerated progress on FCV infrastructure would be a constructive development.

10.6 Coordinate Federal and State Fiscal Policies toward PEVs

In a competitive market economy, a new technology, in order to be sustainable, must be appealing to consumers without tax advantages and subsidies (Sallee 2010). A case can be made that a promising technology with environmental advantages should receive some limited, time-restricted tax advantages and/or subsidies in order to determine whether the technology has long-term promise.

Fiscal policies toward PEVs should not be made in isolation. Policy makers need to consider how to establish a level playing field for PEVs relative to other promising technologies such as mild hybrids, HEVs, advanced diesel technology, cellulosic ethanol, and hydrogen fuel cells. Congress has recently made the following decisions: (1) did not extend the $3,400 tax credit for HEVs, which expired in 2010, but EPA is providing some special GHG compliance credits for hybrid trucks; (2) allowed subsidies and tax credits for ethanol to expire, but EPA is gradually expanding ethanol blending requirements; and (3) most recently authorized the $8,000 federal tax credit for FCVs.

Fiscal policy makers at the federal and state levels are making tax and subsidy policies toward PEVs without coordination of their efforts and without a shared understanding of the proper magnitude, duration, and instrument of support. As a result, it is possible that tax dollars are not being used efficiently (Sallee 2010).

Given the current state of PEV technology, consensus building is needed regarding three questions. (1) Should fiscal policy be encouraging, neutral, or discouraging to a consumer's decision as to whether to purchase a PEV? (2) If a favorable fiscal stance is selected, what is the most cost-effective way for fiscal policy makers to stimulate commercialization of PEVs? (3) If consumer purchases of PEVs are to be subsidized, how long should the subsidies last? In the context of answering those questions, fiscal policy makers need to appreciate how expensive PEVs are currently, how much those costs may decline between now and 2025, and what can be learned from the experience with fiscal policies in the U.S. and abroad.

10.61 Even with Forecasted Declines in Battery Prices, BEVs are not likely to be Cost Competitive in 2025

It is critical to consider consumer receptivity to PEVs in light of their costs (Dumortier et al. 2015; Siddiki et al. 2015; Helveston et al. 2015). If vehicle manufacturers price PEVs using standard costing and retail markup procedures, then the cost of a PEV to the consumer is likely to be substantial—much more than a conventional hybrid, an advanced diesel, or a more fuel-efficient version of the internal combustion engine. Exactly how much more costly it will be is uncertain because (1) lithium ion battery packs are the single largest source of cost, (2) the cost of manufacturing those battery packs is closely-held, proprietary information, and (3) the cost of battery packs is declining and is projected to decline significantly over the next decade (Baker, Chon, and Keisler 2010; Weiss et al. 2012; Orcutt 2015).

Nonetheless, we start with some cost figures from the NHTSA 2012 RIA that are similar to figures in (CARB 2011a, ES–4). We then offer additional insight based on NRC (2015b). We focus on PEVs rather than FCVs because, despite recent technical breakthroughs, FCVs are significantly more expensive than PEVs. We focus on BEVs rather than PHEVs because BEVs receive full credit under the ZEV program.

NHTSA (2012a) estimated that a small BEV would cost $14,581 more than a baseline 2010 gasoline powered car. NRC (2010) warned that steep drops in the cost of producing lithium ion batteries are not likely. Nonetheless, more recent data has shown significant cost reductions and by 2025 the additional cost was projected by NHTSA (2012) to decline to $7,899.

An additional consumer cost of $1,000—equipment plus installation—should be added for a 240 volt home charger, since it reduces the time for a full charge from 12-18 hours with a standard 110 volt outlet to 4-6 hours (NRC 2015b; E3 2014). That technology allows the BEV owner to obtain a full charge overnight and then drive up to 70-100 miles the next day without recharging (NRC 2015b).

Not much has been released publicly in the U.S. about the degree to which the cost of producing lithium ion batteries has declined recently. One international study reviewed all of the publicly available information and concluded that the costs of battery packs have been declining by 14% per year from 2007-2014 and thus the BEV may already be approaching cost competitiveness with the gasoline engine (Nykvist and Nilsson 2015). More recently, IEA (2016) reported that the rapid decline in battery prices appears to have slowed in 2015-16. NRC (2015b) concluded that the BEV cost projections in NHTSA's 2012 RIA remain valid today. The TAR (2016) also suggests that a cost premium for BEVs will remain in 2025, a claim also asserted through independent analysis by energy economists in the U.S. (Covert, Greenstone, and Knittel 2016).

10.62 Federal Tax Credits for PEVs Have a Scheduled Phase Out

NRC (2015b) emphasizes that the decline of battery production costs is occurring only gradually and probably not fast enough, given the planned phase out of the federal income tax credits for PEVs. The federal tax credit for the cost of the 240-volt charger has already expired (2011) and was not renewed. The $7,500 tax credit for the PEV purchaser begins to phase out after a manufacturer produces 200,000 PEVs.

Nissan, Tesla, and General Motors are likely to be the first manufacturers to reach the 200,000-unit threshold, and probably will do so before 2025 (Cole 2017). In 2015 and 2016, Tesla was the largest seller of PEVs in the U.S. and the company's new Model X is only in its first full year of availability. Although more than 400,000 consumers have put $1,000 down toward a purchase of the forthcoming Tesla Model 3 (scheduled for 2018), those consumers may not realize that the federal tax credit may no longer exist when they make their purchase (Cole 2017).

Proponents of PEVs are disappointed that the U.S. Congress did not adopt the Obama administration's repeated request to liberalize the federal tax credit (i.e., enlarge it to $10,000 and require the dealers to make the rebate at the point of sale). NRC (2015b) recommends that Congress consider an enlargement of the manufacturer quotas or some extension of the federal income tax credit. A drawback to this approach is the equity concern: about 90% of the PEV credits go to taxpayers in the top income quartile (greater than $75,000 per year) (Sparshott 2015). Meanwhile, IEA (2016) reports that several countries are planning phase outs of the subsidies for PEVs, typically prior to 2025, arguing that the PEV technology is now available and should sink or swim on its own.

10.63 State Fiscal Policies toward PEVs Are Fragmented and Inconsistent

State fiscal policies toward PEVs are quite fragmented and inconsistent (Graham et al. 2014). In many cases, state policies are not coordinated with federal regulatory or fiscal policy.

Some state legislatures are enlarging cash incentives for PEVs, some are reducing or rescinding them, and some are beginning to tax PEVs on the grounds that they do not contribute to road-repair funding. With regard to encouraging PEVs through electricity-pricing reforms (e.g., time of use pricing), progress is slow. Thus, the future outlook for state-level support for transportation electrification is murky.

California has the longest history of a significant cash rebate for PEVs, but the available funding has been constrained; the maximum size of the rebate for BEVs has been reduced from $5,000 to $2,500, and the rebate is no longer provided to some high-income households that are likely to consider a PEV (CVRP 2012; S. Edelstein 2015; Hirsch 2011). California once gave out free Level-2 chargers to owners of Leafs and Volts, including up to $2,250 toward the cost of charger implementation, but the federal funds for those giveaways are no longer available. The California legislature recently awarded CARB only half of its $230 million request for PEV subsidies under the Clean Vehicle Rebate Project (Mulkern 2016).

Massachusetts and Connecticut recently enacted new cash rebates for EVs, but Illinois and Georgia have eliminated their cash rebates (DeMorro 2015a; DeMorro 2015b; Sawyers 2015; LaReau 2015). Colorado now has the most generous state-level PEV rebate ($5,000) and it is offered at the point of sale rather than at the end of the tax year (Von Kaenel 2016).

Meanwhile, 10 states have passed new legislation to impose fees on the registration of alternatively fueled vehicles (PEVs and HEVs). Fees for PEVs specifically range from $50- $200. In nine of the states, these are annual fees added to regular vehicle registration fees. Other states are considering similar legislation (Atiyeh 2015).

The registration fees applied to PEVs are unlikely to contribute significantly to government funding of road construction and repairs (Dumortier, Kent, and Payton 2016). But, those fees may complicate the social marketing of PEVs and therefore work at cross purposes with a national policy of transport electrification. Thus, there is a clear need for stronger consensus building about PEVs at the national and state levels of government.

The financial case for a PEV purchase is enhanced if electricity prices are low and/or if time-of-use (TOU) rate structures are employed, with low rates at night when many PEVs would be recharged (Ryan and Lavin 2015). But, some ZEV states (e.g., Massachusetts) have relatively high electricity prices and, more generally, states have been slow to adopt TOU rate structures due to public and business opposition. A recent study of a TOU rate scenario in California found lower net revenues for the utility and its ratepayers but lowered costs for delivered energy and higher net benefits for PEV owners, which encourages PEV adoption (IFC 2015).

State utility agencies could also help the electrification effort by allowing power producers to charge ratepayers for the cost of installing an initial network of public charging stations. While Oregon has passed legislation that directs state government to move in this direction, other states, such as Kansas and Missouri, have denied requests to charge ratepayers for the cost of public recharging infrastructure (Uhlenhuth 2016; Tomich 2016).

An unexpected boost for PEV recharging infrastructure came with Volkswagen's recent settlement of the diesel-emissions scandal. VW agreed, as part of the settlement, to spend $80 million in California and $1.2 billion in the rest of the U.S. on ZEV infrastructure and public education about ZEVs over the next 10 years (von Kaenel 2016). The details as to how VW will implement this part of the settlement are not yet known, and coordination issues with other federal and state policies are unresolved.

10.64 International Experience Suggests That, if Fiscal Incentives Are Large Enough, Consumers Will Purchase and Use PEVs

The country of Norway has demonstrated that incentive-based policies can achieve a PEV penetration rate of 25%, without any ZEV-like regulation (Hovland 2015; Kane 2015). U.S. policy makers can learn from the Norwegian experience, even if the specifics of Norway's policies are judged to be inapplicable or inappropriate for the U.S.

The Norwegian subsidy policy for PEVs is actually a complex combination of policies that evolved over the last 10-15 years (Jolly 2015). Elements of the policy include an exemption from the Value Added Tax (VAT) and other taxes on vehicle sales, free public parking spaces in the city, free use of toll roads and ferry connections, free access to bus and HOV lanes, a 50% lower tax on company cars, a 50% lower annual motor vehicle tax, and free recharging of batteries at publicly-funded charging stations.

Although the Norwegian policy has succeeded in promoting PEV sales, a recent evaluation points to some perverse effects (e.g., encouragement of families to purchase a second car and to refrain from walking, biking, and using public transit). Moreover, the subsidy package costs roughly $13,500 per ton of CO avoided, a figure that is cost ineffective compared to other feasible investments in carbon control (Holtsmark and Skonhoft 2014). There are also some reports that policymakers in Norway are planning to phase out PEV subsidies, in part because they are not fiscally sustainable (Hovland 2015; Kane 2015).

Norway is not the only country to stimulate substantial commercialization of ZEVs. The Netherlands has achieved a 10% PEV penetration rate, again with incentive-based policies. For a recent survey of international policies toward PEVs, see IEA (2016).

10.65 The Large Tax Credit or Consumer Rebate May Not be the Most Cost-Effective Method of Stimulating Consumer Interest in PEVs

The U.S. Congressional Budget Office (CBO) has examined the consequences of the $7,500 federal tax credit for PEV purchases and noted some concerning ramifications (CBO 2012). Households claiming the credit often have high incomes, and many would have purchased the PEV even without a credit. A disproportionate share of the credits are awarded to residents of California, in part due to the preferences of California consumers but also due to the ZEV regulation, the HOV lane access for PEVs on congested California freeways, and the relatively high fuel prices in California (often $1.00 gallon or more greater than the U.S. average). The credits typically change purchasing behavior in the most fuel-efficient segment of the new vehicle market (subcompact and compact cars), but the segment with the highest rate of GHG emissions is in the growing consumer market for light trucks. Additionally, PEV sales stimulated by the federal credit allow automakers to sell more fuel-inefficient vehicles and still comply with federal performance standards. Thus, it is not apparent that the $7,500 credit makes a near-term contribution to GHG control or fleet-wide fuel economy.

An alternative approach to public subsidies is to rapidly increase the number of U.S. motorists who have an affordable opportunity to test drive a PEV and, if intrigued, use the vehicle for a week (Bühler et al. 2014). A large body of evidence suggests that test drives and hands-on experience with a PEV is a potent way to increase PEV awareness, generate positive attitudes, and proliferate the word-of-mouth talk about transport electrification (Plug In America 2016; Graham-Rowe et al. 2012). In other words, instead of investing $7,500 in foregone federal revenue on a tax credit for a high-income PEV purchaser, the same amount of money might be better spent providing 75 consumers with a $100 subsidy to rent a PEV for a week.

Another flaw in the $7,500 federal credit is that it has the practical effect of encouraging a small car owner or Prius owner to trade in their vehicle for a small PEV. That does not save much gasoline. Encouraging a pickup truck buyer to purchase a hybrid or diesel truck would save much more gasoline. The hybrid truck credit might save four gallons of gasoline per dollar of subsidy; helping the Prius buyer might save 1.1 gallons per dollar of subsidy (Sallee 2010). Thus, the efficiency of federal tax policy in achieving energy and environmental objectives needs to be reconsidered.

10.66 Fiscal Policies toward PEVs Should be Coordinated with Regulatory Policies

Fiscal policies and regulatory requirements tend to be designed by different policy makers at the federal and state levels. Regulators reside in different offices than budget directors.

Greater collaborative efforts need to be made to facilitate coordination of the two types of policies (Roth 2014; McConnell and Turrentine 2010; Jenn, Azevedo, and Michalek 2016). Current fiscal policies tend to favor BEVs and FCVs over PHEVs and HEVs, which is arguably consistent with the current design of the ZEV regulation. However, PHEVs and HEVs are currently a more cost-effective path to GHG control than BEVs (Bandivadekar et al. 2008; Michalek et al. 2011; Traut et al. 2012; Kromer and Heywood 2008; Samaras and Meisterling 2008; Kammen et al. 2008). The current federal and state fiscal policies do nothing to help implementation of the footprint-based federal programs, since they offer no encouragement to consumers who are considering a high-mileage hybrid crossover or a high-mileage diesel-powered sedan or pickup truck (Sallee 2010). Making more of the fiscal policies footprint-based, like current federal regulations, might be a promising and innovative approach to coordination.

10.67 Bipartisan Commission on Fiscal Policy toward AFVs

Given that current fiscal policies toward AFVs are fragmented and inconsistent, we recommend that a bipartisan commission be created to seek more harmonization of fiscal policies. Members of the commission should include legislators (at the federal and state levels), budget officers (at the federal and state levels), regulators, and a wide range of stakeholders including industry, environmental and consumer groups, and fiscal hawks.

10.7 Higher Gasoline Taxes or a National Carbon Tax

A substantial body of economic and policy literature dating back to the 1980s has highlighted the virtues of a carbon tax or higher gasoline tax, either as a substitute or complement to federal CAFE requirements and/or to ZEV requirements (Austin and Dinan 2005; Jacobsen 2013; L. J. White 1981; Crandall et al. 1986; Crandall 1992; Nivola and Crandall 1995; Gerard and Lave 2003; Kleit 2004; Karplus et al. 2013; Knittel 2012). Some analysts suggest that use of a gasoline tax alone is more efficient than any combination of CAFE standards and a gasoline tax (Anderson, Parry, et al. 2011), while others seek to combine CAFE standards with a higher gasoline tax or carbon tax (McConnell 2013).

An important advantage of such price instruments is that they work to reduce gasoline consumption and GHG emissions in the entire 250-million fleet of vehicles on the road while simultaneously encouraging consumers to purchase a more fuel-efficient vehicle. Higher gasoline taxes also help sales of PEVs, since the spread between electricity prices and gasoline prices is widened, thereby underscoring the financial advantage of a PEV compared to a gasoline-powered vehicle.

Another potential advantage of the price instruments is that they could ultimately replace the complex combination of federal and state regulations. The need for favorable fiscal policies toward AFVs would also be lessened, since the tax instruments would create the desired economic incentives for AFVs.

The political feasibility of a higher federal gasoline tax is questionable. Since it would take a large increase in the fuel tax ($1.00 per gallon or more) to have a significant impact on gasoline consumption and GHG emissions, it is hard to imagine a higher fuel tax replacing the federal standards for the foreseeable future (Klier and Linn

2010). The recent multi-year highway funding package passed by Congress was enacted without any serious consideration of a higher gasoline tax. Some states have enacted increases in gasoline taxes for revenue purposes but the small size of those increases is not relevant for the present aims.

Globally, national carbon taxes pegged to the social cost of carbon emissions have been blocked by political opposition (Jenkins and Karplus 2016). A national U.S. carbon tax seems more remote in terms of political feasibility, since the idea has received little attention in Congress since the Obama administration's "cap and trade" proposal was blocked in the Senate in 2009-10.

The range of carbon taxes that are commonly suggested ($10-60 per ton of CO_2) would not have a large impact on gasoline prices or investment in alternative fuels (Burtraw 2016; Morrow et al. 2010). A gallon of gasoline burned produces 8,887 grams of carbon dioxide (CO_2) (NRC 2015a, 98). By means of a back-of-the-envelope calculation, a carbon tax of $10/ton of CO_2 would translate into a $0.10/gallon increase in the price of gasoline. At the same time, additional considerations regarding the share of biofuels used in gasoline (which would remain untaxed in a carbon tax setting) as well as the behavioral response of consumers driving less in response to a carbon tax, pushing down retail fuel prices, might weaken the pass through of a carbon tax into fuel prices even more. In fact, the EIA (2014) estimates that a $10 carbon tax would increase motor gasoline prices by only $0.08 in 2015 (the first year the tax would be implemented). Thus, even a $60/ton carbon tax would raise gasoline prices by a maximum of $0.53 per gallon (excluding the caveats mentioned previously). The failed cap-and-trade proposal in the 2009-2010 Congress would have reached only $26 per ton in 2019 (Sallee 2010).

Such a modest impact of carbon pricing on fuel prices explains why some experts believe that a carbon tax would do little to reduce GHG emissions from the transportation sector (Morrow et al. 2010). But, that outcome may be acceptable on cost-benefit grounds. As long as the carbon tax is pegged to the external (social) cost of carbon emissions, the resulting outcomes for emission control in various sectors should represent the socially efficient results. If carbon taxes fall far short of estimates of the social cost of carbon, implementation of standards and subsidies, as described in this report, seem likely to continue.

11. RECOMMENDATIONS

We have analyzed a complex mix of federal and state regulatory programs, all with similar objectives and each covering the automotive industry. Drawing from our qualitative and quantitative analyses, this section makes a series of recommendations to guide analysts, regulators, and legislators. Some of our recommendations flow directly from our macroeconomic analyses; others flow from our qualitative analysis of the industry, the regulatory programs, and related public policies.

For Analysts

Given that the federal agencies and CARB are finalizing the Technical Assessment Report (TAR), which contains a wealth of valuable technical and cost data, our focus is on guidance for analysts who are exploring regulatory reform options, especially for model years 2022-2025.

1. Regulatory-reform options should be analyzed taking into account the unexpected drop in fuel prices that has occurred since the federal and ZEV rules were developed from 2009-2012, including the downward revision of fuel-price forecasts through 2025.

   The ramifications of lower fuel prices should be explored from a variety of perspectives, including: (1) impacts on the volume of new vehicle sales in the regulatory baseline, as low fuel prices tend to spur consumer interest in purchasing or leasing new vehicles; (2) impacts on fuel economy and GHG emissions in the baseline fleet of vehicles that would be sold if regulations are not tightened from 2022-2025, including the changing size distribution of vehicles (e.g., cars vs. SUVs and trucks) and the likely increases in consumer demand for performance and other fuel-expending vehicle attributes; (3) impacts on trends in vehicle miles of travel, both directly through the price elasticity of travel demand and indirectly due to possible changes in the "rebound effect," as fuel-economy technologies may have a different impact on travel demand in a low fuel-price environment; (4) impacts on consumer pay-back periods for investments in fuel-saving technologies, since lower fuel prices will tend to lengthen the duration of those payback periods; (5) impacts on the resale value of fuel-economy technologies and plug-in electric vehicles; and (6) impacts on consumer willingness to pay a price premium for fuel-economy technologies.

   Although fuel prices are now expected to be more than 25% lower in 2025 than experts thought in 2012, the future paths of both oil and gasoline prices are notoriously difficult to predict. Thus, we recommend that regulatory analyses include sensitivity analyses based on the low, reference, and high fuel-price scenarios published annually by the Energy Information Administration.

2. Regulatory-reform options should be evaluated based on the best available technology information, focusing on key issues that may distinguish one technology from another; realistic estimates of the impacts of multiple technologies need to be obtained.

   The draft TAR (2016) has a wealth of information on the fuel-saving effectiveness and costs of alternative fuel-saving technologies, including PEVs and other alternative-fueled vehicles. However, additional information is required to make objective comparisons of alternative regulatory reforms and technology combinations. Specifically, we urge analysts to consider the following recommendations concerning residual technology issues that have not been adequately addressed in the draft TAR (2016): (1) the fuel-saving effectiveness and costs of various combinations of technologies should be reconsidered, accounting for the fact that there may be negative and positive synergies when multiple technologies are employed in the same vehicle; (2) the assessment of lightweight materials (e.g., aluminum and lightweight steel) should go beyond consideration of production cost and fuel-saving effectiveness and include a broader and more in-depth assessment of long-term impacts on vehicle maintenance and repair expenses, occupant safety, and lifecycle GHG emissions; (3) the assessment of advanced diesel engine technology should go beyond consideration of production cost and fuel-saving effectiveness and include the value of an engine with a longer lifetime, significant performance advantages (e.g., added torque and cargo-carrying capability), and the added cost of emissions controls that will work in real-world driving conditions; (4) the assessment of conventional hybrid technology should go beyond consideration of production cost and fuel-saving effectiveness and consider why consumer demand for conventional hybrids has not risen as much as expected, given the initial success of the Toyota Prius and the favorable results from total cost-of-ownership studies; (5) the assessment of refinements to the internal combustion engine should go beyond consideration of production cost and fuel-saving effectiveness and consider whether there are hidden amenity costs and benefits in the eyes of consumers (e.g., the largely negative reaction of American consumers to dual-clutch transmissions); and (6) the assessment of PEVs should go beyond a consideration of production cost and net energy savings, and consider why the rate of growth of consumer demand for PEVs has been lower than both the government and industry expected, especially given the extensive PEV incentives available at the federal and state levels.

3. When considering how consumers evaluate fuel-economy gains in new vehicle design, agencies should take into account new econometric studies that infer consumer valuations from short-term changes in fuel prices, decades of practical experience with fuel-saving technologies, and recent real-world experience with conventional hybrid engines.

4. Although agencies have made major steps forward in forecasting a realistic baseline set of vehicles for model years 2022-2025, refinements in the forecasted fleet are necessary in order to make valid comparisons to a regulated fleet subject to the 2022-2025 federal and ZEV standards.

   Specifically, the baseline fleet should be refined to account for the following: (1) higher consumer demands for fuel-expending features (e.g., performance, interior volume, and cargo-carrying capability) due to diminished fuel prices and income growth; and (2) higher regulatory demands for fuel-expending features to meet other environmental and safety objectives (e.g., controls on ultra-fine particles from gasoline engines, higher blends of ethanol in gasoline, and advanced airbag systems).

   After the consumer and regulatory demands for fuel-expending features are quantified, additional fuel-economy technologies should be added to the baseline fleet of vehicles to meet the anticipated consumer and regulatory demands. If agencies are uncertain as to which features will be demanded by consumers and regulators, an empirical approach can be used that defines an average annual increase in fuel-expending features (e.g., performance) based on historical data, and that annual average should be projected through model year 2025.

5. Federal agencies should conduct a careful regulatory impact analysis of the combination of the federal CAFE and GHG regulations and the ZEV program, including interactions between the programs that will influence incremental cost and benefit comparisons.

   Specific suggestions for this analysis include the following: (1) since PEVs and FCVs are currently less cost-effective technologies than the advanced gasoline-engine technologies stimulated by the federal programs, the RIA should begin with the federal programs, refined as appropriate, as the baseline; (2) the environmental benefit assessment of the ZEV regulation should take account of the existence of the federal programs, including the fleet-averaging provisions in the federal programs that may nullify any reduction in GHG emissions and gasoline consumption attributable to PEVs and FCVs; (3) the long-run environmental benefits of the technology-stimulating feature of the ZEV regulation should be adjusted to account for the technology stimulation that will occur anyway, due to ongoing advanced battery R&D programs around the world and the federal and state incentives for PEVs and FCVs; (4) the incremental cost assessment of the ZEV regulation should account for savings in expenditures on gasoline engines and related fuel-economy features that are unnecessary or can be downsized due to the presence of an electric propulsion system, and (5) the incremental cost-benefit assessment of the ZEV regulation should be undertaken from both a national and California perspective in order to inform regulators and legislators as to whether the regulation is in the interests of the citizens of both California and the nation as a whole.

6. Federal agencies should estimate the impact of the model year 2022-2025 standards on the volume of new vehicle sales. The vehicle-sales analyses are a crucial input to analyses of employment impacts, environmental and safety impacts, used-car market ramifications, and societal costs and benefits.

   We offer specific guidance on several analytic issues: (1) since there is genuine uncertainty about the vehicle-price impacts of the 2022-2025 standards, sensitivity analyses of sales volumes should be conducted for different assumptions about the size of the price premiums caused by the regulations; (2) consumers should be assumed to be sensitive to the net vehicle-price premium—where the net premium accounts for the incremental costs of complying with the standards (the gross premium)—car-loan costs, insurance charges, sales taxes, energy expenditures, and any changes in vehicle maintenance and repair costs; (3) emphasis should be given to financial impacts that occur within the first three years of vehicle ownership, even though passenger cars and light trucks may be used for up to 30 and 37 years, respectively, since there is a good deal of evidence that new vehicle consumers are short-run oriented; (4) the resale value of vehicles with enhanced fuel economy should be modeled as a function of the fuel-price environment and future miles of travel, with consumers undervaluing the residual value of fuel-saving technology relative to a rational-choice, present-value computation, and (5) NHTSA's rich new data set on miles of travel by vehicle age should be used to compute the magnitude of fuel savings due to regulations.

7. Agency analysts should estimate the macroeconomic impacts of the combinations of regulations using at least several economic indicators (e.g., total employment, GDP, and real disposable income) and some regional or state disaggregation.

   Extending the analytic work presented in this report, future work should: (1) provide updated estimates of the price elasticity of demand for new vehicles; (2) consider impacts not only on the volume of new vehicle sales but demand for add-on features such as powerful engines, leather seats, and advanced navigation systems; (3) examine alternative scenarios of economic impact where automakers are not able to pass on to consumers the higher incremental cost of producing new vehicles, and how the diminished margins of automakers would affect the industry and the U.S. economy; (4) pursue a quantitative assessment of the employment consequences in the U.S. of a significant shift from gasoline engines to PEVs, with emphasis on labor impacts in the supply chains for the two propulsion systems, including gasoline and recharging stations; (5) collect new data on how consumers are choosing to adjust their household budgets (spending and saving patterns) due to savings in gasoline expenses from lower prices and fuel-saving technologies; (6) prepare economic-impact assessments for each of the 50 states rather than the aggregated nine Census regions used in this report; and (7) estimate impacts on average earnings of workers as well as total levels of employment.

For Regulators

In the near future, federal and state regulators need to consider which regulatory-reform options are worthy of more in-depth analysis from the perspective of benefit and cost. Based on this report, we believe the following options are worthy of consideration for further regulatory assessment.

1. CARB and EPA should reconsider the design of the ZEV program, emphasizing ways to enhance the cost-effectiveness of the program and coordinate its requirements with the federal programs. If EPA determines that a ZEV-like program is in the national interest, EPA should consider expanding the California ZEV program into a national ZEV program that replaces or complements the federal CAFE and GHG performance standards.

   Specific reforms worthy of consideration include: (1) stretching out the schedule for meeting ZEV requirements in conjunction with the federal requirements, recognizing how difficult it is to sell the current generation of PEVs and allowing more time for the costs of FCVs to decline and the next generation of improved PEVs to be widely available to consumers; (2) extending the travel or regional-pooling provisions until community readiness in the 10 ZEV states approximates the conditions recommended by NRC (2015c);

and (3) reconsidering the role of PHEVs in ZEV compliance formulas given their superior driving range, greater utility to consumers, and superior cost-effectiveness from the perspective of GHG control.

2. Federal agencies should reconsider the schedule and explore a variety of refinements to the 2022-2025 performance standards to enhance cost-effectiveness.

   Specifically, federally agencies should: (1) consider a fuel-price threshold that would automatically trigger relaxation, continuation, or tightening of the 2022-2025 standards, depending upon how energy markets change and EIA adjusts its fuel-price forecasts in 2020 for the years 2022-2025; (2) consider a stretch out of the timetable for CAFE and GHG compliance to allow more time for the cost of innovative technologies to decline and gasoline prices to rise; (3) clarify and streamline the process for ruling on off-cycle credit applications, thereby enhancing the cost-effectiveness of the federal programs; (4) consider emphasizing total cost-of-ownership information in consumer-facing educational programs about fuel-economy technologies and ZEVs; (5) harmonize the credit-trading programs and other compliance flexibilities, and (6) reconsider the role and schedule for compliance incentives for PEVs and FCVs, depending on whether the ZEV program is retained or how it is refined.

For Legislators

The federal and state regulatory programs will not work optimally unless legislators take steps to coordinate the regulatory statutes and authorize cost-effective incentives for consumer use of advanced technologies. Some of the necessary legislation must be enacted at the federal level while other components require action by state legislators.

We do not focus here on promising alternatives to the federal and state regulations (e.g., a national carbon tax, higher gasoline taxes) because, despite a large literature on the superior economic case for such alternatives, politicians in the U.S. have been reluctant to enact those alternatives. The legislative suggestions below are highlighted for further consideration and dialogue among stakeholders and should not be considered immediate policy recommendations.

1. The U.S. Congress should commission an independent assessment of the national costs and benefits of the California ZEV program, given the growing stringency of the federal performance standards and fiscal policies designed to promote plug-in electric vehicles. Although the federal agencies may decide to prepare such an assessment, the U.S. Congress should seek a separate look at the issue from an independent body such as the Congressional Budget Office or the National Research Council.

2. Both EPA and CARB are taking the position that a national cost-benefit assessment of the ZEV program is not permissible under the current statutory language of the Clean Air Act. Congress should consider whether to revise the Clean Air Act and require such a national cost-benefit assessment of ZEV waiver decisions.

3. The U.S. Congress should consider new legislation to fully harmonize the federal CAFE and GHG programs, including the credit-trading programs, the penalties for non-compliance, and the compliance-flexibility provisions.

4. The U.S. Congress should commission a bipartisan commission of federal and state legislators and stakeholders to assess the future of consumer incentives for PEVs and FCVs, taking into account the recent reports from the NRC (2015a; 2015b) and new studies of the impact of consumer incentives in the U.S. and abroad. The Commission should consider how incentives should be coordinated with the federal and state performance standards and when the incentives should be scheduled for a phase out.

5. Given that older vehicles account for a disproportionate share of GHG emissions, smog-inducing pollutants, fuel consumption, and safety problems, legislatures should consider cost-effective steps to accelerate the phase-out of older vehicles, taking into account the lessons learned from the "cash-for-clunker" programs evaluated in the U.S. and Europe.

APPENDIX I:
Sensitivity Analyses of Fuel Prices

The GHG and CAFE standards for model years 2017-2025 are projected to reduce gasoline consumption by 4 billion barrels of oil over the entire lifetimes of the vehicles. Applying a 3% discount rate, this reduction results in estimated monetary savings ranging from $459 billion (2010 baseline fleet) to $471 billion (2008 baseline fleet). The monetary benefits derived from reduced fuel consumption represent 80% of the combined benefits of the federal 2017-2025 standards; environmental and energy-security benefits account for most of the remaining 20% (NHTSA 2012a).

To arrive at the estimated monetary savings, NHTSA and EPA used gasoline price projections based on the early release of the 2012 Annual Energy Outlook (AEO) of the Energy Information Administration (EIA). The projection path included the following prices per gallon of gasoline: $3.53 in 2015, $3.76 in 2020, $4.04 in 2030, and $4.57 in 2050. In its 2011 RIA, CARB made similar assumptions for gasoline prices ($4.06 for 2020, $4.02 for 2025, and $4.17 for 2030). The AEO 2012 forecasts only extended as far as 2040. The agencies, however, considered fuel savings over the entire lifetime of the vehicles and, as a result, required fuel price projections as far as 2061. The projected fuel prices for the period 2041-2061 were estimated by NHTSA using an average growth rate of 1.47%.

The monetary savings estimated by the agencies do not include federal and state fuel taxes as these taxes are viewed as income transfers. However, when considering the savings experienced by consumers, fuel taxes were incorporated in the analysis.

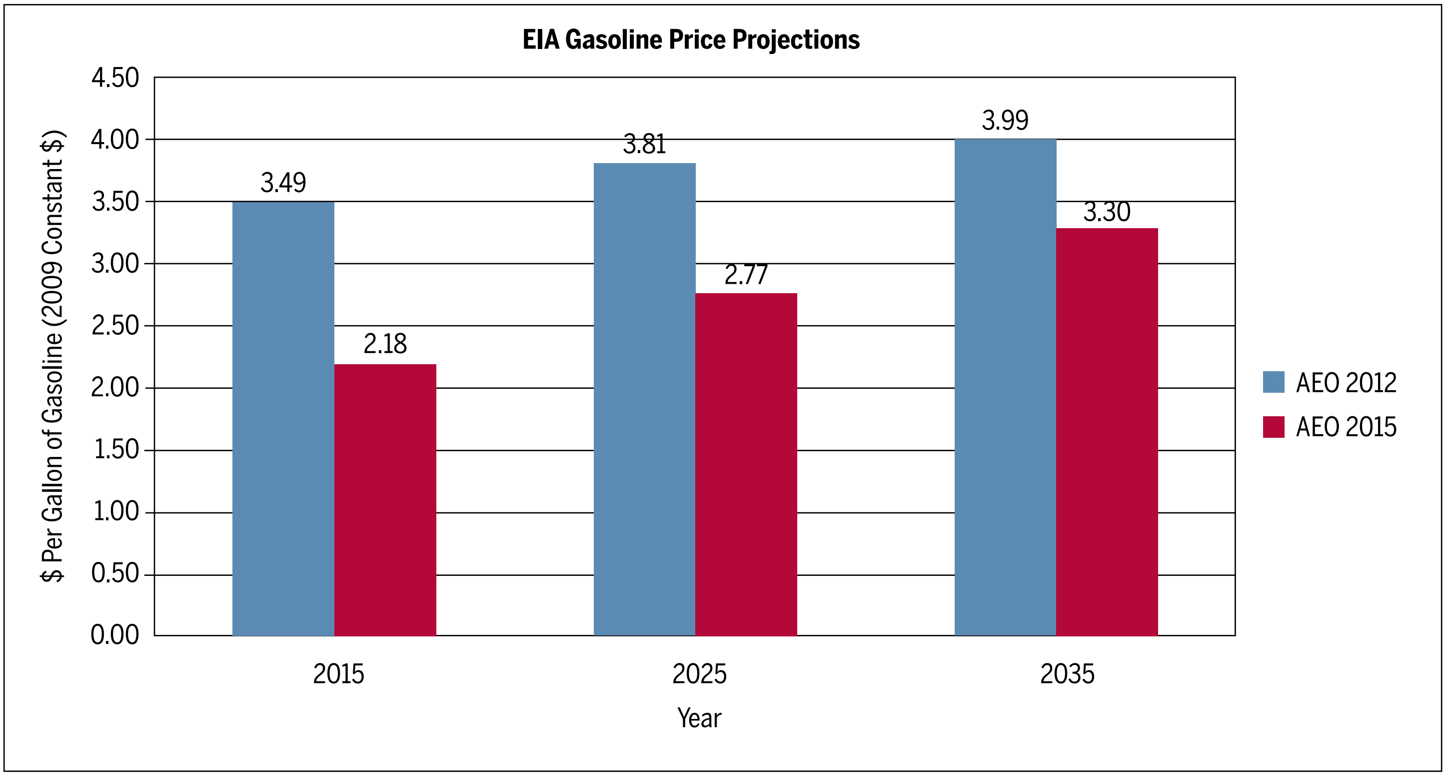
Since the development of the final 2017-2025 federal and ZEV rules, the world oil market has undergone significant changes. The rate of growth in global demand for oil has tapered as the growth of the Chinese economy has slowed and as economic difficulties have plagued the economies of the EU and other regions. On the supply side, the success of unconventional technologies has boosted U.S. and Canadian oil production (Luskin and Warren 2015). Iraq has resumed its production, Iran may expand production, and both Russia and Saudi Arabia have chosen to defend market share rather than reduce production (IEA 2015; Gold 2015; Faucon and Said 2015; Kantchev and Said 2015; Sheppard and Raval 2015).

The subsequent drop in gasoline prices in the U.S. has been significant, with the national average price in 2015 being $2.31 (EIA 2015b). EIA forecasts the average national price of fuel at $2.74 in 2020 and $3.20 in 2030. Figure I.1 illustrates gasoline price projections from AEO 2012—which are the projections used by the agencies in setting the regulations—and AEO 2015 (calculated in constant 2009 dollars). The difference between the AEO 2012 forecast for 2015 and the observed price was $1.31 per gallon. Differences of similar magnitudes are estimated for 2025 ($1.04) and to a lesser extent for 2035 ($0.69). The price path based on the AEO 2015 projections deviates substantially from the 2012 AEO reference case projections and, if applied to the analysis conducted by the agencies, would result in a downward revision of the estimated benefits of the rules.

The large degree of uncertainty regarding long-run oil and gasoline prices is acknowledged by EIA (EIA 2015b; 2015a). Each year, EIA reports both a reference case and low and high gas-price scenarios. For 2020, those projections are $2.56, $2.18, and $3.88, in 2009 constant dollars, respectively. We encourage agency analysts to compute consumer payback periods based on all three scenarios for gasoline prices in 2020-2025, using the most recent EIA forecasts.

With regard to the commercial future of PEVs, the difference between fuel prices and electricity prices also needs to be considered. DOE's eGallon tool was developed to make this comparison easy for consumers (Leistikow 2013). The tool uses the most recent data on gasoline and electricity prices to compare how much money consumers will pay for energy during a trip of the same length. On January 18, 2016, DOE reported the average cost of gasoline in the U.S. as $2.00 per gallon; the price of electricity, in DOE's eGallon format, was $1.16 per gallon. The advantage for electricity was much larger in California ($2.84 per gallon of gasoline vs. $1.36 per

Figure I.1. Gasoline Price Forecasts Based on AEO 2012 and AEO 2015.



Note: The 2015 figure of $2.18 is obtained from the 2015 Short Term Energy Forecast (not the 2015 Annual Energy Outlook). All prices are calculated in 2009 constant dollars.

Source: EIA, 2012; EIA, 2015b; calculations made by the authors.

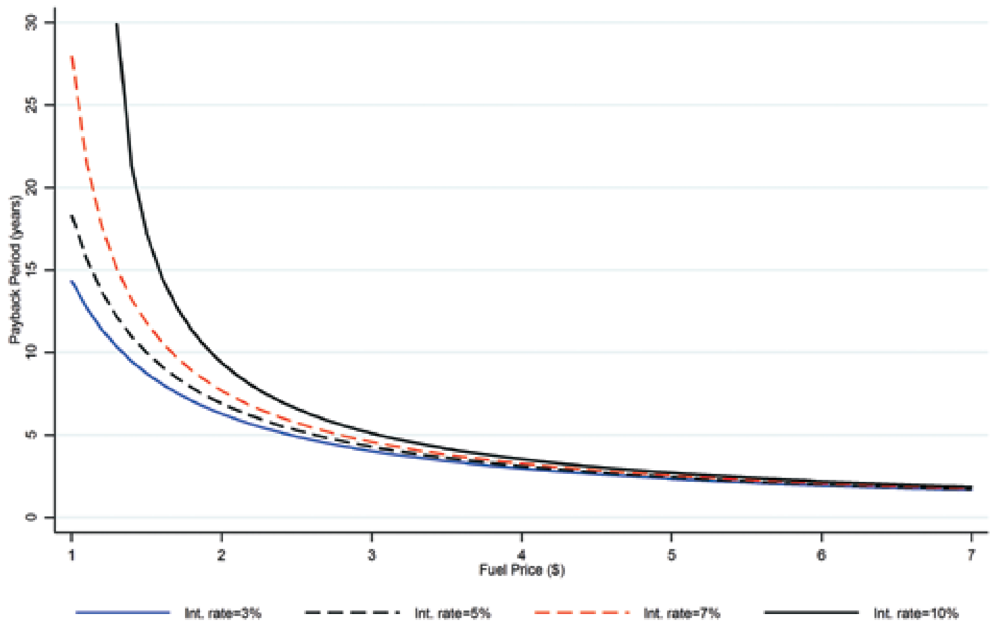
eGallon) than it was in Massachusetts ($1.97 per gallon for gasoline vs. $1.67 per eGallon). Looking forward, agencies need to consider the projected pathways for both electricity and gasoline prices, especially in the ZEV states.

In order to illustrate the powerful impact of lower fuel prices on the appeal of fuel-efficient vehicles and PEVs, we calculate consumer payback periods for a range of fuel prices and four discount rates. The results from this analysis are presented in Figures 2, 3, and 4 for incremental price impacts of $2,000, $5,000, and $10,000, respectively. The lower price corresponds roughly to extensive modification of a gasoline-powered vehicle, the mid-range prices correspond roughly to an HEV or an advanced diesel engine, and the higher price corresponds roughly to a future PEV. In assessing the consumer payback periods, it may be useful to consider the rough rule of thumb that a typical new vehicle purchaser expects payback for a fuel-economy investment in three years (NRC 2015a; CAR 2011; Greene, Evans, and Hiestand 2013).

The results show that consumer payback periods are lengthened substantially at low fuel prices. For example, Figure I.2 shows that a $2,000 investment in fuel economy is defensible at $4 per gallon; the payback period is less than five years regardless of the discount rate. The investment is far less attractive when fuel price is $2 per gallon, especially at higher interest rates. Similarly, Figure I.3 shows that the payback period for a price premium of $5,000 is not attractive at fuel prices under $7 per gallon. Finally, Figure I.4 shows that, at a price premium of $10,000, a PEV might pay for itself after 12 years of driving, assuming gasoline costs $4 per gallon and a 5% discount rate. At $2 per gallon, it takes almost 40 years of driving for the investment to pay off.

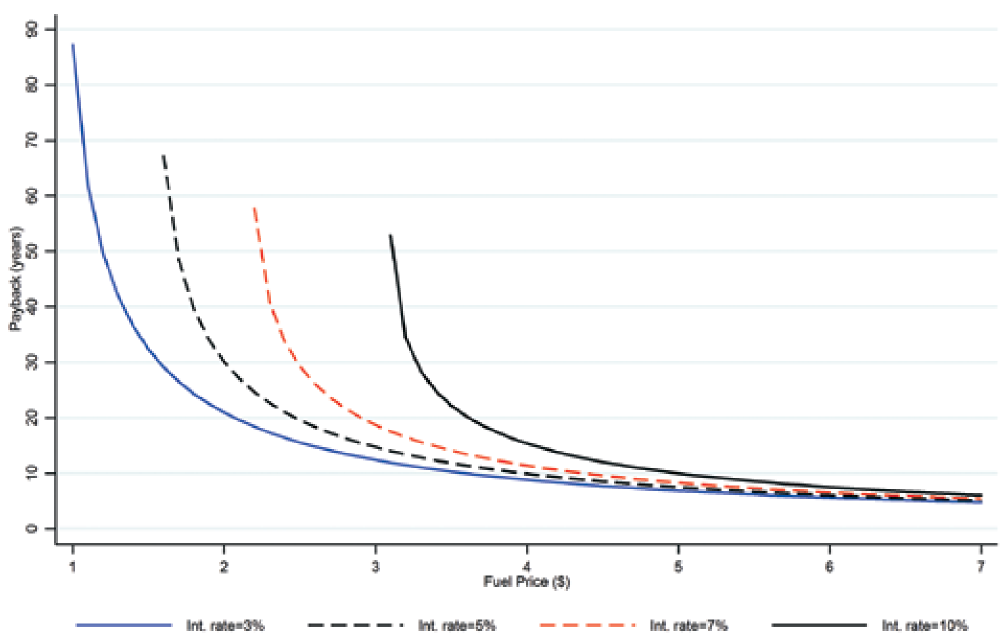
An independent assessment of the consumer's perspective found that the three most important variables to the consumer are the price of the fuel-saving technology, the fuel price, and the expected number of miles driven.

Figure I.2. Consumer Payback (in Years) Analysis for a 55 MPG Vehicle with an Incremental Price of $2,000.



Note: Reported is the payback period (in years) required to recoup the $2,000 incremental cost of buying a fuel efficient vehicle under various assumptions about interest rates and fuel price. We assume the consumer drives 12,500 miles per year, that the inefficient car gets 35 MPG, and that the efficient vehicle gets 55 MPG. We further assume that on-road fuel economy is 80% of the stated fuel economy and that the incremental resale value of the efficient vehicle is 10% of the incremental cost. The analysis assumes that all parameter values are constant over the life of the vehicle, which implies that fuel savings are constant across time.

Figure I.3. Consumer Payback (in Years) Analysis for a 55 MPG Vehicle with an Incremental Price of $5,000.



Note: Reported is the payback period (in years) required to recoup the $5,000 incremental cost of buying a fuel efficient vehicle under various assumptions about interest rates and fuel price. We assume the consumer drives 12,500 miles per year, that the inefficient car gets 35 MPG, and that the efficient vehicle gets 55 MPG. We further assume that on-road fuel economy is 80% of the stated fuel economy and that both vehicles have the same resale value. The analysis assumes that all parameter values are constant over the life of the vehicle, which implies that fuel savings are constant across time.

The authors conclude that “the reality is that higher fuel economy levels currently envisioned in CAFE are not expected to be economically viable at current fuel prices” (Simmons et al. 2015). Below, we explore recent evidence about how consumers weigh these factors when purchasing a new car or light truck.

Lower fuel prices may also influence a series of other analytical parameters in the RIAs (see Appendix III). Here we offer another example of a variable—the rebound effect—that needs to be reconsidered in a low fuel-price environment.

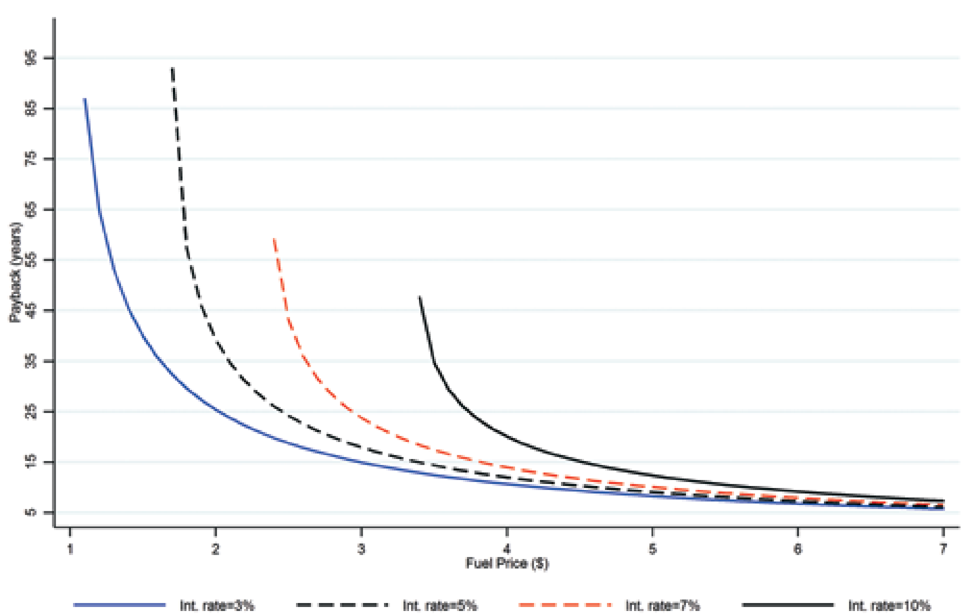
A significant literature has addressed the “rebound effect,” that is, the behavioral phenomenon whereby drivers of fuel efficient vehicles tend to increase their vehicle miles traveled due to the lower fuel cost per mile of travel.

The federal agencies conducted a thorough review of the literature and assumed a rebound rate of 10% which, at the time the RIAs were published (2012), captured the consensus among the peer reviewed literature. However, recent work has found a declining rebound effect over time.

Hymel and Small (2015) use data from 1966-2009 and find that consumers respond more to fuel price increases than decreases. As a result, they report a greater rebound effect in years when fuel prices are rising. Furthermore, they find that the rebound effect declines in magnitude as household income rises. This income effect can be justified based on the fact that, as income levels increase, the driver’s time plays a predominant role in the variable cost of travel, and decreases the role of fuel prices. In another recent study, Gillingham, Jenn, and Azevedo (2015) report a short run gasoline price elasticity of driving of 10% for drivers in Pennsylvania, with substantial heterogeneity demonstrated among drivers. Drivers of low fuel economy vehicles exhibit high rates of gasoline price elasticities of driving, while drivers of fuel efficient vehicles demonstrate inelastic behaviors.

During the midterm reviews, analysts should examine carefully how lower fuel prices could influence each of the variables in the consumer payback analyses. Emphasis should be given to how low fuel prices influence, directly and indirectly, consumer payback periods and new vehicle sales.

Figure I.4. Consumer Payback (in Years) Analysis for a PEV with an Incremental Price of $10,000.



Note: Reported is the payback period (in years) required to recoup the $10,000 incremental cost of buying a PEV under various assumptions about interest rates and fuel price. We assume the consumer drives 12,500 miles per year, that the inefficient car gets 35 MPG, and that the efficient vehicle gets 105 MPG (the equivalent of a BEV100 [35kWh]). We further assume that on-road fuel economy is 80% of the stated fuel economy and the incremental resale value of the efficient vehicle is -10% of the incremental cost. The analysis assumes that all parameter values are constant over the life of the vehicle, which implies that fuel savings are constant across time.

APPENDIX II:
Review of European and American Experiences with Cash-for-Clunkers Program

The cash-for-clunkers idea originated in France in the 1980s, as the government sought to reduce pollution and boost the fortunes of the French-owned automotive companies and their workers (Wald 2009). The idea spread rapidly to Germany, Italy, Spain, the UK, and Ireland (Dial 2011; Schoenfeld and Walker 2009). Both the U.S. and selected European countries experimented with cash-for-clunker programs in the 2005-2010 period, primarily to stimulate the depressed levels of new vehicle sales. Many U.S. states currently have such programs, though they vary in their design. Some of the state programs have no focus on environmental gain, while others focus on removing older vehicles with poor environmental performance.

Evaluations of cash-for-clunker programs have yielded mixed results, both with respect to stimulus effects and environmental impacts. The programs increase new vehicle sales temporarily, but sales are much lower when the incentive is removed (Gayer and Parker 2013; Knittel 2009). It appears that the cash incentive influences precisely when the owner of an old vehicle decides to purchase a new one, but the earlier purchase may be less than a year ahead of when it would have been otherwise (Mian and Sufi 2012).

The stimulus effect is minimal or negative if new vehicle purchases are restricted to greener vehicles, since overall spending on vehicles may fall or not increase (Hoekstra, Puller, and West 2014). Programs that do not regulate the environmental profile of the new vehicle may have adverse effects on the environment, as the cash incentive may cause the consumer to buy a larger and more polluting vehicle than they would have acquired without the cash incentive, as that was the perverse experience in Germany (Kloßner and Pfeifer 2015). The programs do not necessarily benefit low-income households, as higher-income households are more likely to take advantage of the cash incentive, and the programs may raise prices on older used cars—those often purchased by income-constrained households (Gayer and Parker 2013; Sawyers 2009, April 7; Sawyers 2009; Woodyard 2009).

Programs that require cash rebates to be used for green vehicles, such as the U.S. Cars Allowance Program (CAP), do report environmentally positive results (NHTSA 2009). The CAP, which triggered the replacement of 680,000 old vehicles with new vehicles, induced the consumer to accelerate their new vehicle purchase by an average of 2.87 years. Those vehicles were typically driven 10,000-12,500 miles per year. The average EPA mileage rating of the new vehicles was 9.2 MPG higher than the average rating of the retired vehicles (24.9 vs. 15.7 MPG). As a result, CAP was associated with significant reductions in fuel consumption, GHG emissions, and criteria pollutants that are linked to the formation of smog and soot (NHTSA 2009). Other studies find smaller but still substantial differences in the mileage ratings: 2.5-5.0 MPG higher ratings for the new vehicle compared to the retired vehicle, in part because the retirements are often SUVs and pickup trucks while the new vehicles are often small cars (Hoekstra, Puller, and West 2014; Kellogg and Mitchell 2009; Curtin 2009).

The cost-effectiveness of the pollution reductions from CAP are unattractive when compared to the social cost of carbon or carbon prices (Li, Linn, and Spiller 2013; Knittel 2009), but properly designed cash-for-clunker programs may still be more cost-effective at the margin than the ZEV regulation. The midterm reviews should explore such a comparison.

APPENDIX III:
Toward a More Realistic Baseline Fleet of Vehicles

When estimating the impact of stricter standards on new vehicle sales, agencies need a realistic baseline fleet of vehicles to use for comparison purposes (NRC 2015a). The baseline is the fleet of vehicles that would be sold to consumers if CAFE/GHG standards were frozen at their 2016 levels, or at the 2021 levels, if the focus is the model year 2022-2025 standards. The characteristics of those vehicles (price, fuel economy, and other attributes) can then be compared to the characteristics of the vehicles subject to the stricter standards (price, fuel economy, and other attributes). If the regulated vehicles are more attractive to consumers, then the volume of new vehicle sales should increase; if they are less attractive, new vehicle sales should decline.

In the final rulemaking for model years 2017-2025, EPA/DOT started with a simulated fleet of 2016 vehicles as improved by the 2011-2016 standards (i.e., fuel-economy certification data for the 2010 fleet was used as a baseline and then fuel-saving technologies were applied until the simulated 2016 fleet was in compliance with the 2016 standards). Other vehicle attributes such as performance (e.g., horsepower and acceleration capability) and safety (e.g., number of airbag systems in the vehicle) were held constant from 2010-2016.

Both NHTSA (2012a) and NRC (2015a, 320, 363) have pointed out that it is not realistic to assume that, in the absence of stricter standards for 2017-2025, fuel-expending improvements such as increased performance and enhanced safety would not have been implemented by automakers. A robust body of historical data does show that, as technological advances proceed, automakers deliver more performance, acceleration capability, and fuel economy to consumers (EPA 2015). Without pressure from regulation or high fuel prices, innovation tends to be channeled to performance and acceleration capability instead of fuel economy (Knittel 2011). Those improvements in performance and safety, if foregone by the stricter 2017-2025 standards, represent an “opportunity cost” of the stricter standards that should be analyzed (NRC 2015a, 327). However, it is difficult to know exactly what those characteristics would have been and how consumers would have valued them.

A tractable approach to addressing this issue, which we recommend for consideration, is to assign a fuel economy penalty in the baseline 2017-2025 fleet for the projected improvements in performance and safety that producers would deliver in response to consumer and regulatory demands. For example, in 2002 NRC recommended that NHTSA assign a 3.5% weight penalty in the baseline fleet for future safety and smog-related emissions requirements (NRC 2002, 66, 76, 112). NHTSA has found that some safety systems do add to the weight of the vehicle (Tarbet 2004). The extra vehicle weight can then be assigned a fuel economy penalty using standard methods. EPA has indicated that stricter regulations of vehicles may be necessary to address the ultra-fine particles emitted from gasoline-powered vehicles, and compliance with those regulations would likely entail a fuel-economy penalty.

Likewise, it would be reasonable to assume a 1% or 2% annual gain in horsepower in the baseline fleet to meet consumer demand, and an associated fuel economy penalty for the added horsepower (EPA 2015). If evidence suggests that consumers do not notice small changes in horsepower or other attributes, then this complexity does not need to be addressed. The available evidence on consumer transactions does suggest that some consumers are sensitive to marginal changes in performance (Klier and Linn 2012).

The consequence of the fuel economy penalties is that a more extensive and costly set of fuel economy technologies are necessary to bring the baseline fleet into compliance with the 2017-2025 standards. The cost of those additional technologies (with deductions for the fuel savings) are then incorporated into the analysis of vehicle prices and impacts on new vehicle sales and employment.

An advantage of this approach is that the agencies can maintain their preferred analytic assumption that safety and performance will not be affected by the regulatory requirements. All that changes are vehicle price and fuel economy, and those characteristics can readily be linked to new vehicle sales with established methods and data.

APPENDIX IV:
Regulatory Impact Analyses Model Parameters

In their RIAs, NHTSA, EPA, and CARB document several economic parameters that were used as inputs in their consumer-payback modeling efforts. The assumptions they made about those parameters affected, among other things, the estimated effects the regulations would have on consumer benefits and payback periods, new vehicles sales, and the overall benefits of the regulations. In our report, we have discussed some of those input parameters extensively (i.e., technology costs, gasoline prices, and rebound effect). In this Appendix, we present additional parameters that were used by the agencies in the RIAs.

Price Elasticity for Automobiles

The agencies assume a price elasticity of demand for automobiles equal to -1. That figure implies that a 1% increase in the price of an automobile will decrease sales by 1%, all else equal. The assumption used by the agencies is that automobile manufacturers will be able to pass on the increase in cost of production, due to implementation of fuel efficient technologies, to consumers.

Automobile Insurance Cost

NHTSA and EPA use data from the National Bureau of Economic Analysis to calculate the average price of a new passenger car in 2010 at $24,572 and that of a new light truck at $31,721. Considering those two estimates, the agencies calculated the average price of a new vehicle in 2010 to be $27,953. The latter is the figure based on which insurance costs were calculated. The agencies assumed that costs of collision and comprehensive insurance for the first five years in the life of a new vehicle, expressed in percentage terms of the price of the vehicle, decline based on the following schedule: 1.86% for year one, 1.82% for year two, 1.75% for year three, 1.64% for year four, and 1.50% for year five. In aggregate, the overall cost of insurance for the first five years of the vehicle's life is 8.5% of the original price. The CARB RIA assumes an insurance premium of 6.6%.

Automobile Loan Cost

NHTSA and EPA assumed that 70% of consumers finance their automobile purchases through a loan at an average rate of 5.16% for a period of 48 months. The relevant interest rate used by CARB was slightly higher at 5.35%. The literature on automobile purchases suggests that some consumers use their credit cards to make car payments (Busse, Knittel, and Zettelmeyer 2013). If that is the case, then the financing interest rate one would need to consider to estimate the actual cost of purchasing a new car is the interest rate consumers pay on their credit cards.

Vehicle Resale/Residual Value

NHTSA assumes that the average resale value of a vehicle five years into its lifetime is 35% of its original price. The present value of this percentage using a 3% discount rate yields an effective residual value of 30.64%. The equivalent figure used in the EPA RIA is 23% (assuming a 7% discount rate), while the CARB RIA assumes a resale value of 39% (using a 5% discount rate).

Average Period of Automobile Ownership

EPA and NHTSA considered the full lifetime of cars to be 30 years and trucks to be 37 years, while CARB considered the median lifetime of a passenger car in California to be 14 years. For vehicles of a given model year, EPA and NHTSA calculate the probability that vehicles remain in service after the year they are sold. The resulting "survival rate" is used to calculate the number of vehicles in service at a specific time period. This is the first step in estimating fuel consumption. The next step requires an estimate of Vehicle Miles Traveled (VMT). The latter is produced by using the Federal Highway Administration's 2009 National Household Travel Survey

(2011). The VMT projections made by the agencies align closely with the EIA (2012) early release projections and are illustrated in Table IV.1. From a consumer perspective, average auto ownership for new car buyers is estimated to be only 2-5 years, significantly lower than the total lifetime of a vehicle considered by the agencies.

Automobile Sales Tax

NHTSA and EPA use a national weighted average sales tax of 5.46% in their regulatory impact assessments, computed by weighting the most recent automobile sales tax by state (as of when the assessments were performed) by census population by state. Census population was used as the weighting parameter instead of new vehicle sales by state, though the latter was preferable, due to data availability limitations. As a proxy for new vehicles sales, NHTSA used new vehicle registrations by state. The tax rate resulting from the registration-based proxy of new vehicle sales was negligibly different from that produced using census population data. The California sales tax used in the CARB RIA is 7.25%.

Fuel Efficiency Rebound Rate

Both NHTSA and EPA estimate the rebound rate associated with increased fuel efficiency at 10%, though the agencies use different ranges in their sensitivity analyses. NHTSA uses a range of 5-20% for sensitivity testing, whereas EPA uses a range of 0-20%. CARB assumes a declining rebound rate based on the following schedule: 6% in 2012, 5% in 2020, and 3% in 2030.

On Road Fuel Economy Gap

Both NHTSA and EPA assume a 20% fuel economy gap for liquid fuel and a 30% gap for vehicles with an electric drivetrain.

Discount Rate Applied to Future Fuel Savings

NHTSA and EPA conduct their regulatory impact assessments assuming 3% and 7% discount rates on future fuel savings. These are the standard social discount rates federal agencies apply in their regulatory impact assessments, as recommended by the Office of Management and Budget (OMB). The OMB sets standard discount rates for regulatory impact assessments in light of substantial variation in the literature on the appropriate valuations of such, particularly across regulatory domains. The CARB uses a 5% discount rate for future fuel savings in its regulatory impact analysis.

Table IV.1. Survival Weighted Per-Vehicle Reference VMT Used in the RIAs

	MY 2021		MY 2025	
	Cars	**Light Trucks**	**Cars**	**Light Trucks**
EPA	204,161	218,399	209,037	223,688
NHTSA	206,768	218,812	211,795	223,865

Source: EPA and DOT, 2012

APPENDIX V:
ZEV Price Premium

In this Appendix we provided a detailed explanation of the methodology for the ZEV premium calculation. All the values for the BEV and PHEV premiums are presented in Table V.1. For each vehicle technology (PHEV20, PHEV40, BEV75, BEV100, and BEV200), we calculate the price premium for small and standard cars and then obtain the average of the two (highlighted in blue in Table V.1).

Tables V.2 and V.3 contain information on the price premium of four components of EVs, namely: (1) Car batteries, (2) Non-Battery Items, (3) In-Home Chargers, and (4) Labor Cost for In-Home Charger Installation. Each Table contains a separate panel for each of the following vehicle technologies: PHEV20, PHEV40, BEV75, BEV100, and BEV200. Table V.2 has information on the standard car class and Table V.3 on the small car class. The first five rows of each panel in Tables V.2 and V.3 contain data from the TAR (2016). All lines pertain to Total Costs (i.e. Direct Manufacturing Costs + Indirect Costs). A detailed list of the data documentation for those five line items is provided in Table V.4. The last two lines in every panel of Tables V.2 and V.3 calculate the total price premium of each vehicle technology using battery pack cost estimates from DOE (2013). To obtain those estimates we followed the methodology discussed below.

Calculation of Battery Pack Costs Using DOE Cost Estimates

DOE (2013) forecasts a target battery cost of $125/kWh by 2022, with a starting cost of $300/kWh in 2013 (NRC 2015b). We use those two data points to interpolate the battery costs for years 2017-2021. We assume that the $125/kWh cost will remain constant for year 2023 onwards. The resulting battery costs are presented in Table V.5. We use the data from the TAR (2016) regarding projected battery capacities (presented in Table V.6) and apply them to the DOE battery cost estimates of Table V.5. The final battery cost calculations based on the DOE projected are provided in Table V.7 where we incorporate the Indirect Costs assumption of the TAR (2016). The total price premium for the various vehicle technologies presented in the last line of each panel in Tables V.2 and V.3 assumes the same Non-Battery Items cost, In-Home Charger cost and Labor for In-Home Charger installation as the TAR (2016).

Equation (1) illustrates the calculations that lead to the ZEV premium:

$$
\begin{aligned}
ZEV\_premium_t &= Min\_ZEV\_floor_t * 30\% \\
&* \left\{ \left[PHEV\_category_{share_t} \sum_{i=1}^{2} * \left(PHEV_{share_{it}} * PHEV_{premium_{it}} \right) \right] \right. \\
&+ \left. \left[(1 - PHEV\_category_{share_t}) \sum_{j=1}^{2} \left(BEV_{share_{jt}} * BEV_{premium_{jt}} \right) \right] \right\} \quad (1)
\end{aligned}
$$

where:

t=Model Year with t=2017,..., 2025

i is an indicator variable where 1=PHEV10 and 2=PHEV40
j is an indicator variable where 1=BEV100 and 2=BEV200

$PHEV\_category\_share_t$ is given in Table 7.5 (note that 1-PHEV_category_share = BEV_category_share)
BEV_share_{jt} and $PHEV\_share_{it}$ are given in Table 7.6
$Min\_ZEV\_floor_t$ is presented in Table 7.7
$BEV\_premium_{jt}$ and $PHEV\_premium_{it}$ are given in Table 7.11
30% captures the proportion of vehicles sold in the 10 ZEV states.

Table V.1. Price Premiums for Different Types of PEVs and Vehicle Classes

			Model Year								
	Vehicle Class	Data Source	2017	2018	2019	2020	2021	2022	2023	2024	2025
PHEV20	Small	TAR (2016)	$10,135	$9,839	$9,142	$8,931	$8,746	$8,582	$8,436	$8,305	$7,504
	Standard		$11,115	$10,792	$10,005	$9,773	$9,570	$9,391	$9,230	$9,087	$8,214
	(Sm+St)/2		$10,625	$10,316	$9,574	$9,352	$9,158	$8,987	$8,833	$8,696	$7,859
PHEV40	Small	TAR (2016)	$12,643	$12,258	$11,391	$11,115	$10,874	$10,663	$10,472	$10,302	$9,260
	Standard		$14,728	$14,241	$13,200	$12,879	$12,599	$12,353	$12,132	$11,932	$10,726
	(Sm+St)/2		$13,686	$13,250	$12,296	$11,997	$11,737	$11,508	$11,302	$11,117	$9,993
BEV75	Small	TAR (2016)	$10,905	$10,473	$10,115	$9,812	$9,550	$9,321	$9,118	$8,939	$7,594
	Standard		$12,644	$12,155	$11,747	$11,401	$11,102	$10,840	$10,608	$10,401	$8,876
	(Sm+St)/2		$11,775	$11,314	$10,931	$10,607	$10,326	$10,081	$9,863	$9,670	$8,235
	Small	DOE (2013)	$8,027	$7,550	$7,048	$6,524	$5,979	$5,415	$5,461	$5,506	$4,836
	Standard		$10,195	$9,602	$8,980	$8,330	$7,655	$6,957	$7,006	$7,055	$6,216
	(Sm+St)/2		$9,111	$8,576	$8,014	$7,427	$6,817	$6,186	$6,233	$6,280	$5,526
BEV100	Small	TAR (2016)	$ 12,300	$ 11,807	$ 11,397	$ 11,051	$ 10,751	$ 10,490	$ 10,258	$ 10,052	$ 8,532
	Standard		$ 14,941	$ 14,353	$ 13,863	$ 13,448	$ 13,088	$ 12,774	$ 12,495	$ 12,336	$ 10,420
	(Sm+St)/2		$ 13,621	$ 13,080	$ 12,630	$ 12,250	$ 11,920	$ 11,632	$ 11,377	$ 11,194	$ 9,476
	Small	DOE (2013)	$ 10,206	$ 9,576	$ 8,911	$ 8,217	$ 7,493	$ 6,744	$ 6,806	$ 6,868	$ 6,020
	Standard		$ 12,952	$ 12,170	$ 11,346	$ 10,486	$ 9,591	$ 8,666	$ 8,736	$ 8,894	$ 7,726
	(Sm+St)/2		$ 11,579	$ 10,873	$ 10,128	$ 9,351	$ 8,542	$ 7,705	$ 7,771	$ 7,881	$ 6,873
BEV200	Small	TAR (2016)	$ 17,485	$ 16,764	$ 16,166	$ 15,658	$ 15,220	$ 14,838	$ 14,498	$ 14,197	$ 12,000
	Standard		$ 19,809	$ 19,005	$ 18,338	$ 17,770	$ 17,281	$ 16,853	$ 16,473	$ 16,134	$ 13,673
	(Sm+St)/2		$ 18,647	$ 17,885	$ 17,252	$ 16,714	$ 16,251	$ 15,846	$ 15,486	$ 15,166	$ 12,837
	Small	DOE (2013)	$ 15,860	$ 14,832	$ 13,746	$ 12,607	$ 11,421	$ 10,191	$ 10,299	$ 10,405	$ 9,080
	Standard		$ 19,886	$ 18,614	$ 17,272	$ 15,865	$ 14,401	$ 12,884	$ 13,010	$ 13,134	$ 11,473
	(Sm+St)/2		$ 17,873	$ 16,723	$ 15,509	$ 14,236	$ 12,911	$ 11,538	$ 11,655	$ 11,770	$ 10,276

Note: Values are in 2013 constant dollars.

Table V.2. Total Cost Data for Four Components of PHEV20, PHEV40, BEV75, BEV100, and BEV200 (Standard Cars)

			Model Year								
	Component (Standard Car)	**Net WR**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
PHEV 20	Car Battery	6	6,454	6,171	5,935	5,735	5,563	5,412	5,278	5,159	4,317
	Non-Battery Items	6	3,514	3,478	2,930	2,900	2,871	2,845	2,820	2,797	2,775
	In-Home Charger		72	68	65	63	61	59	57	56	47
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	PHEV 20 premium (TAR)		11,115	10,792	10,005	9,773	9,570	9,391	9,230	9,087	8,214
PHEV 40	St Car Battery	5	8,670	8,251	7,936	7,669	7,438	7,237	7,058	6,898	5,772
	Non-Battery Items	5	4,547	4,500	3,791	3,752	3,715	3,681	3,649	3,618	3,590
	In-Home Charger		436	415	398	383	371	360	350	341	289
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	PHEV 40 premium (TAR)		14,728	14,241	13,200	12,879	12,599	12,353	12,132	11,932	10,726
BEV 75	Car Battery	10	10,444	9,986	9,604	9,281	9,002	8,758	8,542	8,349	6,986
	Non-Battery Items	10	648	640	633	626	620	614	609	604	499
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 75 premium (TAR)		12,644	12,155	11,747	11,401	11,102	10,840	10,608	10,401	8,876
	Car Battery (DOE)		7,995	7,433	6,837	6,210	5,555	4,875	4,940	5,003	4,326
	BEV 75 premium (DOE)		10,195	9,602	8,980	8,330	7,655	6,957	7,006	7,055	6,216
			Model Year								
	Component (Standard Car)	**Net WR**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
BEV 100	Car Battery	7	12,660	12,104	11,642	11,250	10,911	10,615	10,353	10,119	8,468
	Non-Battery Items	7	729	720	711	704	697	691	685	769	561
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 100 premium (TAR)		14,941	14,353	13,863	13,448	13,088	12,774	12,495	12,336	10,420
	Car Battery (DOE)		10,671	9,921	9,125	8,288	7,414	6,507	6,594	6,677	5,774
	BEV 100 premium (DOE)		12,952	12,170	11,346	10,486	9,591	8,666	8,736	8,894	7,726
BEV 200	Car Battery	8	17,553	16,781	16,141	15,597	15,128	14,718	14,355	14,030	11,740
	Non-Battery Items	8	704	695	687	679	673	667	661	656	542
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 200 premium		19,809	19,005	18,338	17,770	17,281	16,853	16,473	16,134	13,673
	Car Battery (DOE)		17,630	16,390	15,075	13,692	12,248	10,749	10,892	11,030	9,540
	BEV 200 premium (DOE)		19,886	18,614	17,272	15,865	14,401	12,884	13,010	13,134	11,473

Note: All costs are in 2013 constant dollars and pertain to a standard car.

Source: TAR (2016). A detailed list of the exact source Tables in the TAR for each vehicle technology is provided in Table I.4.

Table V.3. Total Cost Data for Four Components of PHEV20, PHEV40, BEV75, BEV100, and BEV200 (Small Cars)

	Model Year										
	Component (Small Car)	**Net WR**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
PHEV 20	Car Battery	6	5,921	5,661	5,445	5,262	5,104	4,965	4,843	4,733	3,961
	Non-Battery Items	6	3,067	3,035	2,557	2,531	2,506	2,483	2,461	2,441	2,421
	In-Home Charger		72	68	65	63	61	59	57	56	47
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	PHEV 20 premium (TAR)		10,135	9,839	9,142	8,931	8,746	8,582	8,436	8,305	7,504
PHEV 40	St Car Battery	6	7,469	7,141	6,868	6,637	6,437	6,263	6,108	5,970	4,996
	Non-Battery Items	6	3,724	3,685	3,105	3,073	3,043	3,015	2,988	2,963	2,940
	In-Home Charger		375	357	343	330	319	310	301	294	249
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	PHEV 40 premium (TAR)		12,643	12,258	11,391	11,115	10,874	10,663	10,472	10,302	9,260
BEV 75	Car Battery	10	9,401	8,988	8,645	8,354	8,103	7,883	7,688	7,515	6,288
	Non-Battery Items	10	(48)	(44)	(40)	(36)	(33)	(30)	(27)	(24)	(85)
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 75 premium (TAR)		10,905	10,473	10,115	9,812	9,550	9,321	9,118	8,939	7,594
	Car Battery (DOE)		6,523	6,065	5,578	5,066	4,532	3,977	4,031	4,082	3,530
	BEV 75 premium (DOE)		8,027	7,550	7,048	6,524	5,979	5,415	5,461	5,506	4,836
			Model Year								
	Component (Small Car)	**Net WR**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
BEV 100	Car Battery	8	10,792	10,318	9,924	9,590	9,301	9,049	8,826	8,626	7,218
	Non-Battery Items	8	(44)	(40)	(37)	(33)	(30)	(27)	(25)	(22)	(77)
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 100 premium (TAR)		12,300	11,807	11,397	11,051	10,751	10,490	10,258	10,052	8,532
	Car Battery (DOE)		8,698	8,087	7,438	6,756	6,043	5,303	5,374	5,442	4,706
	BEV 100 premium (DOE)		10,206	9,576	8,911	8,217	7,493	6,744	6,806	6,868	6,020
BEV 200	Car Battery	8	15,977	15,275	14,692	14,197	13,770	13,397	13,066	12,771	10,686
	Non-Battery Items	8	(44)	(40)	(36)	(33)	(30)	(27)	(25)	(22)	(77)
	In-Home Charger		477	454	435	419	405	393	382	373	316
	Labor Cost for In-Home Charge Installation		1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
	BEV 200 premium		17,485	16,764	16,166	15,658	15,220	14,838	14,498	14,197	12,000
	Car Battery (DOE)		14,352	13,343	12,272	11,146	9,971	8,750	8,867	8,979	7,766
	BEV 200 premium (DOE)		15,860	14,832	13,746	12,607	11,421	10,191	10,299	10,405	9,080

Note: All costs are in 2013 constant dollars and pertain to a small car.

Table V.4. Sources of Data Regarding Four Cost Components of PEVs Presented in Tables I.2 and I.3

	PHEV20	PHEV40	BEV75	BEV100	BEV200
Car Battery	Table 5.126	Table 5.127	Table 5.128	Table 5.129	Table 5.130
Non-Battery Items	Table 5.91	Table 5.92	Table 5.93	Table 5.94	Table 5.95
In-Home Charger	Table 5.96	Table 5.97	Table 5.98	Table 5.98	Table 5.98
Labor Costs for In-Home Charger Installation	Table 5.99	Table 5.99	Table 5.99	Table 5.99	Table 5.99

Note: All table numbers are from the TAR (2016).

Table V.5. Direct Manufacturing Cost of Battery Packs Based on DOE (2013) Target Cost Information

	Model Year								
	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC of battery packs based on DOE target (in $2013/kWh)	222	203	183	164	144	125	125	125	125

Source: DOE 2013, NRC 2015

Table V.6. Battery Capacity in kWh for BEV75, BEV100, and BEV200 by Vehicle Class (Small and Standard Cars)

	BEV75		BEV100		BEV200	
	Small	Standards	Small	Standard	Small	Standard
Battery Capacity in kWh	19.5	23.9	26	31.9	42.9	52.7

Source: TAR 2016, Table 5.112

Table V.7. Total Cost of Batteries for BEV75, BEV100, and BEV200 by Vehicle Class (Small and Standard Cars)

			Model Year								
Vehicle Technology	**Vehicle Class**		**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
		IC/DMC ratio	0.505	0.534	0.560	0.585	0.609	0.632	0.654	0.674	0.448
BEV75	Small	DMC	4,333	3,954	3,575	3,196	2,817	2,438	2,438	2,438	2,438
		TC	6,523	6,065	5,578	5,066	4,532	3,977	4,031	4,082	3,530
	Standard	DMC	5,311	4,846	4,382	3,917	3,452	2,988	2,988	2,988	2,988
		TC	7,995	7,433	6,837	6,210	5,555	4,875	4,940	5,003	4,326
BEV100	Small	DMC	5,778	5,272	4,767	4,261	3,756	3,250	3,250	3,250	3,250
		TC	8,698	8,087	7,438	6,756	6,043	5,303	5,374	5,442	4,706
	Standard	DMC	7,089	6,469	5,848	5,228	4,608	3,988	3,988	3,988	3,988
		TC	10,671	9,921	9,125	8,288	7,414	6,507	6,594	6,677	5,774
BEV200	Small	DMC	9,533	8,699	7,865	7,031	6,197	5,363	5,363	5,363	5,363
		TC	14,352	13,343	12,272	11,146	9,971	8,750	8,867	8,979	7,766
	Standard	DMC	11,711	10,686	9,662	8,637	7,612	6,588	6,588	6,588	6,588
		TC	17,630	16,390	15,075	13,692	12,248	10,749	10,892	11,030	9,540

Note: The DMC (Direct Manufacturing Cost) is expressed in 2013 constant dollars and was calculated using the battery pack cost figures in Table A.4 and the battery capacity figures in Table A.5. The TC (Total Cost) rows were calculated by multiplying the DMC rows by 1+(IC/DMC ratio). The latter was obtained from the TAR (2016).

APPENDIX VI:
Objective Function and Constraints of COMET Model

In the COMET model, the objective function is:

$$\min_{\text{wrt } x_{ijtp}^{\text{pack}}} y^{\text{totalCost}} = \sum_{ijtpk} \frac{c_{ijk}^{\text{sales}} c_{ijk}^{\text{packCost}} x_{ijtp}^{\text{pack}}}{\left(1+c^{\text{dr}}\right)^{t}},$$

where y is total cost to the individual manufacturer, i is vehicle model, j is vehicle technology type, k is vehicle class, t is the time period, and p is the technology package. The term c represents model parameters, which are exogenous inputs from EPA input files, and x represents model variables that the optimization problem varies, all with superscript descriptors. The dr descriptor denotes a discount rate which is meant to replicate credit banking behavior.

We constructed the model to include four constraints: (1) the CAFE and GHG constraint; (2) the technology package constraint; (3) the maximum penetration of a technology package; and (4) the ZEV mandate. The notation for the constraints is as follows:

The CAFE/GHG constraint

$$\sum_{t} \left(c_{tk}^{\text{GHG}} - \frac{\sum_{i \in itok,\, jkp} c_{ijk}^{\text{sales}} c_{ij}^{\text{emRate}} x_{ijtp}^{\text{pack}}}{\sum_{i \in itok,\, j} c_{ijk}^{\text{sales}}} \right) \geq 0, \forall k;$$

technology package constraint

$$\sum_{j \in itoj,\, p \in ptoj} x_{ijtp}^{\text{pack}} - 1 = 0, \forall it;$$

maximum penetration of technology package

$$c_{jp}^{\text{packCap}} - x_{ijtp}^{\text{pack}} \geq 0, \forall ijtp;$$

and the ZEV mandate

$$\frac{\sum_{ijpk} x_{ijtp}^{\text{pack}} c_{ijk}^{\text{sales}} c_{jp}^{\text{isEV}}}{\sum_{ijk} c_{ijk}^{\text{sales}}} - c_{t}^{\text{ZEV}} \geq 0, \forall t.$$

Examples of COMET model parameters are presented in Table VI.1.

COMET accommodates a straightforward integration of regulatory requirements outside the current capability of the OMEGA model, which allows us to include the CAFE and GHG emissions standard as well as the ZEV mandate in the COMET scenarios.

The CAFE and GHG standards are harmonized and operate at a continuously more stringent rate over time. The standards are not uniform across all manufacturers; the compliance value is dependent on the fleet weighted-average footprint for each automaker.

Table VI.1. Examples of Model Parameters Used in COMET

	Description	Example
Sets		
I	Vehicle model	v1.4.1: Compact (Honda), v1.4.56: Civic (Honda)
J	Vehicle technology type	LargeAuto
K	Vehicle class	C/T (car or truck)
T	Time period	2016 (year)
P	Technology package	Indexed technology package, e.g. package 1: Auto 4VDI4+LUB+EFR1+ASL1+LDB+DCP+WR0%+6sp
Parameters		
$c_{ijk}^{\text{packCost}}$	Cost of a specific technology package	$147 for technology package 1
c^{dr}	Banking discount rate	15%
c_{tk}^{GHG}	EPA GHG standard requirement by vehicle class and year	249 grams/mi for Honda in 2014
c_{ij}^{emRate}	Base vehicle emissions rate	Vehicle index 1119 has a base emissions of 404.6 grams/mi
c_{jp}^{isEV}	Boolean denoting whether vehicle technology is an EV package	1 for EV technology, 0 for gasoline technology
c_{t}^{ZEV}	ZEV requirement	0.6% requirement for manufacturers in 2018

The calculation for determining a manufacturer's compliance pathway uses the values seen in Table VI.2 as follows:

$$f(x) = \begin{cases} a, & xc + d \le a \\ b, & xc + d \ge b \\ xc + d \end{cases}$$

The equation above describes the rules for determining the emission rate requirement for each manufacturer. For example, suppose the sales-weighted footprint for a manufacturer in the passenger car segment is 50 sq ft. in 2016. This manufacturer's requirement in 2016 can be calculated as follows since $a<50*c+d<b$:

$$50 \times 4.72 + 12.7 = 248.7$$

If, however, the sales-weighted footprint for the manufacturer is 40 sq ft. in 2016, a>40*c+d and the manufacturer is below the floor and thus the emission rate requirement is 206 grams/mi. Likewise, if the sales-weighted footprint is 60 sq ft. in 2016, the manufacturer is above the ceiling since c<60*c+d and therefore the emission rate requirement is capped at 277 grams/mi.

Table VI.2. abcd Values for CAFE/GHG Emissions Standard Compliance

	Passenger Cars				Light Trucks			
Year	a	b	c	d	a	b	c	d
2014	228	299	4.72	34.8	275	376	4.04	109.4
2015	217	288	4.72	23.4	261	362	4.04	95.1
2016	206	277	4.72	12.7	247	348	4.04	81.1
2017	194.7	262.7	4.53	8.9	238.1	347.2	4.87	38.3
2018	184.9	250.1	4.35	6.5	226.8	341.7	4.76	31.6
2019	175.3	238	4.17	4.2	219.5	338.6	4.68	27.7
2020	166.1	226.2	4.01	1.9	211.9	336.7	4.57	24.6
2021	157.2	214.9	3.84	-0.4	195.4	334.8	4.28	19.8
2022	150.2	205.5	3.69	-1.1	185.7	320.8	4.09	17.8
2023	143.3	196.5	3.54	-1.8	176.4	305.6	3.91	16
2024	136.8	187.8	3.4	-2.5	167.6	291	3.74	14.2
2025	130.5	179.5	3.26	-3.2	159.1	277.1	3.58	12.5

The ZEV mandate requires that a percentage of vehicles distributed for sale by larger-volume manufacturers consist of ZEVs, as classified by CARB under the regulatory program. The annual requirements for zero-emissions vehicles are presented in Table VI.3. This compliance timeline is based on the annual sales of vehicles in ZEV regions and the ZEV standard over time. While the actual composition of the electric vehicle requirement is more nuanced, in COMET there is a flat requirement for all manufacturers to meet regardless of which type of electric vehicle is adopted, such as a BEV75 or a BEV200.

Table VI.3. Estimated National Zero-Emission Vehicle Requirements by Model Year

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Proportion ZEV Requirement	0.006	0.006	0.006	0.006	0.006	0.012	0.018	0.024	0.03	0.036	0.042	0.048

Since the technology input files include electrification technologies, COMET selects those particular technologies in the same preferential cost-efficient order as all other scenarios. However, due to the presence of a specific constraint on minimum EV requirements, any solutions that do not meet the ZEV mandate requirement are not legitimate solutions. The final solution from COMET is the most cost-effective method of complying with both CAFE/GHG and ZEV standards. The inclusion of the ZEV mandate results in a higher cost than if just the CAFE/GHG standards are considered. However, COMET accounts for the fact that, when manufacturers produce PEVs to comply with the ZEV regulation, they obtain compliance credits in the federal programs, which makes it somewhat easier to comply with the federal programs.

APPENDIX VII:
Supply Chain Categories

NRC 2015 used the example of the midsize car pathway in order to capture the cost components of achieving the 2025 CAFE standard. The Committee utilized three major categories of technologies: (1) shift from a 2.4L NA Engine to a 1.6L TRBDS, (2) shift from a 6 speed AT transmissions to an 8 Speed AT, and (3) shift to a Lightweight Vehicle Body Structure. Table VII.1 presents the Direct Manufacturing Cost (DMC) information for each of those three technologies, broken down by DMC categories.

Table VII.1. DMC Categories for Midsize Car Compliance with 2025 CAFE Standards

		Labor	Burden	End Item Scrap	Selling, General and	Profit	Engineering, Design & Testing (ED&T)/ Research & Development (R&D)	Total Packaging Cost	Net Cost to OEM
1.6L TRBDS vs 2.4L NA Engine	$218.82	$72.58	$154.24	$11.72	$33.96	$33.12	$12.36	$0.90	$537.70
8 Speed AT vs. 6 Speed AT	$8.49	$15.11	$28.20	$0.69	$4.27	$3.74	$1.34		$61.84
Lightweight Vehicle Body Structure	$580.00	$110.00	$443.00						$1,133.00
TOTAL	$807.31	$197.69	$625.44	$12.41	$38.23	$36.86	$13.70	$0.90	$1732.54

Source: EPA, 2009; EPA, 2011; NHTSA, 2012

In order to better align those categories with our REMI model, we have conducted the re-organization presented in Table VII.2.

The difference between Table VII.1 and Table VII.2 is that in the latter we have merged the following DMC categories:

Table VII.2. Reorganized DMC Categories that Align with REMI Modeling Inputs

	Materials	Labor	Burden	Shareholder Income	ED&T R&D	Total
1.6L TRBDS vs. 2.4L NA Engine	$230.54	$72.58	$155.14	$67.08	$12.36	$537.70
8 Speed AT vs. 6 Speed AT	$9.18	$15.11	$28.20	$8.01	$1.34	$61.84
Lightweight Vehicle Body Structure	$580.00	$110.00	$443.00			$1133.00
TOTAL	$819.72	$197.69	$626.34	$75.09	$13.70	$1732.54
Percentage Share of DMC	47.3%	11.4%	36.2%	4.3%	0.8%	
Percentage Share of Total Cost	32.4%	7.8%	24.8%	3%	0.5%	

(a) Total packaging cost (Table VII.1) has been added to the Burden category in Table VII.2.

(b) End item scrap (Table VII.1) has been added to the Materials category in Table VII.2.

(c) SG&A and Profit (Table VII.1) have been merged into a new category which we call Shareholder income in Table VII.2.

The last two rows of Table VII.2 show the share of each DMC category as a percentage of: (a) DMC and (b) Total Cost (TC). The TC percentages incorporate the 1.46 RPE multiplier used by the EPA. That is, in order to obtain TC, the EPA applied the following adjustment to DMC: TC=DMC*1.46, where Indirect Cost (IC) is the 0.46 adjustment. Therefore, DMC represents 68.5% of TC (i.e. 68.5%=100/146) with IC representing the remaining 32.5% (i.e. 32.5%=46/146). Table VII.3 shows the various IC categories of the RPE multiplier.

Table VII.3. Indirect Cost Categories of the RPE Multiplier

RPE Multiplier Contributor	*Industry Average*
Vehicle Manufacturing	
Cost of Sales	1
Production Overhead	
Warranty	0.03
R&D (product development)	0.05
Depreciation and Amortization	0.07
Maintenance, Repair Operations Cost	0.03
Total Production Overhead	0.18
Corporate Overhead	
General and Administrative	0.07
Retirement	<0.01
Health	0.01
Total Corporate Overhead	0.08
Selling	
Transportation	0.04
Marketing	0.04
Dealers	
Dealer New Vehicle Net Profit	<0.01
Dealer New Vehicle Selling Cost	0.06
Total Selling and Dealer Contributors	0.14
Sum of Indirect Costs	
Net Income	0.06
Other Costs (not included as contributors)	0.04
RPE Multiplier	**1.46**

We have made the following assumptions in order to merge the IC categories of Table VII.3 with the DMC categories in Table VII.2:

(a) Production overhead (with the exception of R&D) and Corporate Overhead in Table VII.3 are part of the Burden DMC category of Table VII.2.

(b) Selling and Dealers categories in Table VII.3 form a new cost category labeled "Dealers."

(c) Net income in Table VII.3 is part of the Shareholders income category in Table VII.2.

Applying the adjustments discussed above results in the percentage shares illustrated in Table VII.4. Table VII.5 combines the information in Table VII.2 and Table VII.4 and shows the final percentage shares in each of the six cost categories.

Table VII.4. IC Categories and Their Shares of IC and TC

	R&D	Production and Corporate Overhead	Dealers	Shareholder
Percentage Share of IC	10.9%	45.7%	30.4%	13%
Percentage Share of TC	3.4%	14.4%	9.6%	4.1%

Table VII.5. Cost Categories as Percentage Shares of TC

Total Cost Components						
	R&D	Overhead/Burden	Materials	Labor	Shareholder Income	Dealers
Percentage Share of TC	4%	39.1%	32.4%	7.8%	7.1%	9.6%

APPENDIX VIII:
Total Cost of Ownership Model of Sales Impacts

Overview

One of our primary objectives is to calculate the sales impact of the CAFE standards. Following NHTSA (2010; 2012c) we calculate the sales impact of CAFE after accounting for the net total cost of ownership. This approach assumes that the consumer considers not only the incremental gross price of buying a new car, but also the effect of the higher price on taxes, insurance, and loan financing. These costs are then netted against any fuel savings as well as any incremental resale value. The final expression used in the calculations can be expressed as follows:

$$\%\Delta S_{it}=(P_{itn}/price_{it})*\varepsilon,$$
$$P_{itn}=P_{itg}-R_{it}-F_{it}-T_{it}-I_{it}-L_{it},$$

Subscript *i* indicates vehicle type (cars and light duty trucks) and subscript *t* indicates model years. $\%\Delta S$is percentage change in vehicle sales, $P_n$is net price premium, $P_g$is gross price premium, *R* is incremental resale value, *F* is fuel savings, *T* is incremental sales tax on new vehicles, *I* is incremental auto insurance costs, *L* is incremental auto-loan financing costs, ε is price elasticity of demand for new vehicles, and *price* is average vehicle price based on EIA (2012) projections.

Our estimates of percentage change in sales are calculated relative to a baseline that holds CAFE standards fixed at 2016 levels (i.e. ~38 mpg for cars and ~29 MPG for trucks).

The analysis begins with a replication of the (NHTSA 2012a) analysis for model years 2017-2025; we refer to this replication as our 2012 Perspective NHTSA. We then make several adjustments to the 2012 Perspective NHTSA approach to account for information that became available after the 2012 RIA was published. Each adjustment is made relative to the 2012 Perspective. Therefore, we are able to show how each change, separately, affects the results.

The 2012 Perspective

The 2012 Perspective represents our attempt to replicate the NHTSA results. As best as possible, we use the same data and assumptions as described in the 2012 RIA. This section describes those data and assumptions.

Price Premium

The 2012 perspective NHTSA uses price premium from the NHTSA 2012 RIA, which reports a premium that increases from \$364 to \$1,578 for MY 2017 to MY 2025 cars, and \$147 to \$1226 for MY 2017 to MY 2025 trucks. All dollar amounts are in 2010 constant dollars. See section 7.2 and Table 7.3 for more information on the NHTSA price premium.

Fuel Economy

The 2012 perspective NHTSA uses fuel economy from the NHTSA RIA, which reports MPG that increase from 39.61 to 55.32 for MY 2017 to MY 2025 cars, and 29.08 to 39.34 for MY 2017 to MY 2025 trucks.

Fuel Price Projections

We use reference fuel price data reported in the RIA (NHTSA RIA, Table VIII-5a, page 866). Prices are projected to increase from \$3.64 in 2017 to \$3.84 in 2025. The 2012 AEO projects fuel prices up to 2040. We extend the fuel projections to 2071 by using a growth rate of 0.7%.

Consumer Valuation of Fuel Savings
This covers several components:

1. Consumer fuel price projections: we follow NHTSA and assume that consumers use the AEO fuel price projections to forecast future fuel prices.
2. Consumer valuation period: we assume consumers value five years' worth of fuel savings.
3. Resale value: we assume the incremental resale value is equal to 35% of the gross premium.

Survival Rate
We use the survival rates published by NHTSA in the 2012 RIA.

Vehicle Miles Traveled
Vehicle miles traveled is based on 2008 data published in the 2009 National Household Travel Survey. We make three adjustments to the 2008 VMT schedule to produce VMT schedules for each model year following the RIA. For example, the VMT for a MY 2017 vehicle of age one (assuming the CAFE standards are increased) is obtained using the following adjustments.

1. Fuel price rebound effect: rebound effect due to change in fuel price between 2008 and 2017: (FuelPrice_2008 - FuelPrice_2017)/ FuelPrice_2008 times the rebound estimate of -0.1. Fuel price in 2008 is $3.37 and the fuel price for 2017 is taken from AEO2012.
2. Fuel economy rebound effect: rebound effect of change in MPG between 2008 and 2017: (MPG_2008 - MPG_2017)/MPG_2008 times the rebound estimate of -0.1. MPG_2008 is 22.66 for trucks and 29.2 for cars, and are taken from AEO 2011 (Table A7, page 130). Note that our calculations use the fleet MPG from 2008 and not the MPG for each model year vehicle that existed in 2008. The 2017 MPG is based on the assumption that the stricter CAFE standards are implemented.
3. Secular growth factor: (1+g)^(9). We follow NHTSA and assume that g=0.6%.

The VMT schedule for a MY 2017 vehicle of age 2 is obtained using the same three adjustments, but replaces the 2017 fuel price with the fuel price for 2018 in step 1, and uses 10 instead of 9 in the exponent of step 3, and so on for older MY 2017 vehicles.

Similarly, the VMT schedule for a MY 2025 vehicle of age 1 is obtained using the following adjustments:

1. Rebound effect due to change in fuel price between 2008 and 2017: (FuelPrice_2008 - FuelPrice_2025)/ FuelPrice_2008 times the rebound estimate of -0.1.
2. Rebound effect of change in MPG between 2008 and 2017: (MPG_2008 - MPG_2025)/MPG_2008 times the rebound estimate of -0.1.
3. Secular growth factor: (1+g)^(17). We follow NHTSA and assume the g=0.6%.

The VMT schedule for a MY 2025 vehicle of age 2 is obtained using the same three adjustments, but replaces the 2025 fuel price with the fuel price for 2026 in step 1, and uses 18 instead of 17 in the exponent of step 3, and so on for older MY 2025 vehicles. These adjustments imply that the VMT schedules vary both within and between MYs. To summarize:

VMT(MY t) = VMT(2008)*Fuel price rebound effect*Fuel economy rebound effect*Secular growth factor*survival rate

We also calculate VMT schedules for each model year under the assumption that CAFE standards remain fixed at their 2016 levels. The procedure is the same as above with the exception that the MPG for each MY (2017-2025) is fixed at the 2016 level.

Other Costs of Ownership
We use the data published in the RIA to model changes in auto-insurance costs, auto-loan financing costs, and sales taxes.

1. The population-weighted average sales tax rate is 5.53%.
2. The auto-loan interest rate is 5.16%, and we assume that 70% of consumers finance their purchase.
3. The auto-insurance costs are based on the assumption that insurance costs are 1.86%, 1.82%, 1.75%, 1.64%, and 1.5% of the vehicle's price over the first five years, respectively, of ownership.

Discount Rate
All dollar amounts are reported in constant 2010 dollars, and are discounted using a discount rate of 7%.

Fuel Savings
The fuel savings are calculated using AEO fuel price projections, survival rate adjusted VMT schedules, and vehicle fuel economy. The fuel economy is converted to gallons per mile (GPM) and corrected for on-road efficiency of 80%. The VMT schedule and GPM are combined to calculate gallons saved, which we define as the difference between gallons consumed under the updated CAFE standards and gallons consumed under the 2016 CAFE standards. This procedure gives us the gallons saved in each year over the life of each model year vehicle. We then multiply gallons saved by fuel price to get fuel savings. Since the consumer only values five years of savings, we find the present value of the fuel savings over the first five years.

The Adjustments
We make several adjustments to the baseline. The adjustment accounts for information that existed in 2012 but was not included in the agency's analyses, as well as information that did not exist in 2012.

ZEV Mandate
We adjust the baseline price premium to account for the fact that zero-emission vehicles (ZEVs) are more expensive than internal combustion engine vehicles. We calculate the sales impacts of three alternative ways of satisfying the ZEV mandate:

1. Use only BEV75.
2. Use only BEV200.
3. Use a mix of BEV100, BEV200, PHEV20, and PHEV40.

In each case, we assume that ZEV states control 30% of the national market, but that the costs of compliance with ZEV will be distributed across cars in the national market. The share of ZEVs that must be sold in each state depends on the type of ZEV. The required share in 2025 is 8.8% if only BEV200s are sold and 16% if a mix of BEVs and PHEVs are sold. The ZEV price premium is taken from the TAR, and also depends on the type of ZEV; the premium in 2025 is $12,153 and $9,171 for BEV200 and mix of BEV and PHEVs, respectively.

The adjusted price premium for the case where the ZEV mandate is satisfied with a mix of BEVs and PHEVs in MY2025 is calculated as follows:

$$P_g=(1-0.3*0.16)*\$1{,}578+(0.3*0.16)*\$9{,}171=\$1{,}942$$

A similar calculation is made for other MYs. We further assume that the ZEV mandate will be satisfied with only cars. In other words, we do not include any ZEV trucks in the analysis. This implies that the ZEV premium on cars is inflated relative to a scenario where a mix of cars and trucks are used to satisfy the ZEV mandate. We illustrate the potential bias of our chosen approach with a simple example in Table VIII.1 below. Panel A of Table VIII.1 shows the ZEV premium adjustment for MY 2025 if we assume the ZEV mandate is met proportionally by cars and trucks. The premium is $170 (=0.4*0.3*0.154*9171) for cars and $285 (=0.6*0.3*0.154*9171) for trucks. The weighted average premium in this case is $455 (=170+285), which is comparable to the figure projected by the agencies.

Table VIII.1. Illustration of ZEV Premium Calculation for MY 2025

Type	MKT Share	ZEV Mandate	Mkt Share of ZEV States	Premium	ZEV Premium
Panel A: ZEV Regulation Met Proportionally by Cars and Trucks					
Cars	40.00%	15.40%	30.00%	$9,171.00	$169.48
Trucks	60.00%	15.40%	30.00%	$10,286.55	$285.14
Weighted average premium					$454.62
Panel B: ZEV Regulation Met with Cars Only					
Cars	40.00%	38.50%	30.00%	$9,171.00	$423.70
Trucks	60.00%	0.00%	30.00%	$10,286.55	$0.00
Weighted average premium					$423.70

Note: Reported in the last column is the incremental cost of a vehicle due to the ZEV regulation. Calculations are based on the assumption that the ZEV regulation is met by a combination of BEVs and PHEVs.

Panel B of Table VIII.1 shows the effect of assuming ZEV is met with only cars. In this case, we have to increase the share of ZEV cars to 38.5% (=15.4%/40%) to account for the fact that all ZEVs will be cars. The average premium for cars is now $424 (=0.4*0.3*0.385*9171). This calculation explicitly accounts for the number of cars that must be sold in order to satisfy ZEV (38.5% of 40% of 30%) without overestimating the number of ZEV vehicles. Similarly, the premium for trucks is $0 (=0.6*0.3*0.0*10287). Importantly, the weighted average ZEV premium for the national fleet is now $424, which is modestly lower than the premium if we assumed both cars and trucks would be used to satisfy ZEV.

Notice that our illustration made the simplifying assumption that the ZEV mandate will be met proportionally by cars and trucks. This is a bold assumption that most surely will not be realized. We believe the actual distribution of ZEV vehicles will be much closer to the assumption in panel B of Table VIII.1; most ZEVs will be cars. Therefore, the bias in our chosen approach should be approximately zero. A more plausible assumption is that automakers satisfy ZEV with cars, but allocate the costs to both cars and trucks. We present results based on this assumption as we assume manufacturers split the ZEV costs equally between cars and trucks.

The method used to account for ZEV costs so far does not account for the interdependence between ZEV and CAFE. Since manufacturers are required to produce ZEVs, and because ZEVs have higher MPG, it is reasonable to assume that compliance with ZEV will reduce the ICE technological requirements needed to satisfy CAFE. The lower technological need implies a lower price premium for ICEs. Failure to account for this interdependence implies that manufacturers will over-comply with CAFE. We relax this assumption by using the COMET model to account for the ZEV premium. The COMET approach also allows for the ZEV premium to apply, separately, to both cars and trucks, but maintains the assumption that ZEV costs are distributed nationally.

Besides accounting for the interdependence between ZEV and CAFE, the COMET approach differs from the back-of-the-envelope approach used above in that the COMET is based solely on BEV75. Additionally, the COMET modeling of ZEV also incorporates the NRC adjustments (discussed below). See section 7.4 for a more detailed discussion of COMET.

NRC Price Premium

The National Research Council (2015a) report on technology costs and fuel-saving effectiveness highlighted two alternative cost scenarios: “high most likely” and “low most likely.” The high most likely case suggests that costs are 56% higher than the NHTSA estimates while the low most likely case suggests costs are 11% higher than the NHTSA estimates. We present results using these two adjustments. In each case we adjust the NHTSA estimates by the amount recommended by NRC. See section 7.2 for a detailed discussion of the NRC adjustments.

Consumer Valuation of Fuel Savings and Resale Value

We consider four adjustments to the way fuel is valued by consumers.

1. Consumers value one year of fuel savings.
2. Consumers value three years of fuel savings.
3. Consumers' forecast of fuel price is myopic; fuel price at time of purchase remains fixed over time.
4. Resale value is equal to 55% of the present value of fuel savings from years six to 30 of the vehicle's life.

Each of these changes is made separately. The resale value calculation is based on the assumption that the first owner believes the value of the fuel saving technology is capitalized in the price of the vehicle. She expects that the vehicle can trade for a premium on the secondary market, and that the premium is based on the present value of fuel savings over the remaining life of the vehicle. If consumers fully valued fuel savings then the premium would be equal to the present value of fuel savings. However, existing evidence is ambiguous on this issue. For this reason, we present results with full and undervaluation. In the current context, we assume the secondary market only values 55% of the fuel savings.

Other Adjustments

We make several other adjustments to capture changes that have taken place since the 2012 RIA.

1. NHTSA published updated VMT estimates in the TAR. We use these VMT estimates in place of the 2008 VMT from the 2012 RIA. The new VMT estimates are for the 2015 fleet. We use the same procedure described above to adjust the 2015 schedule for each model year from 2017-2025.
2. Auto-loan rate and discount rate are set at different values in the baseline model. We adjust this assumption and instead set the auto-loan rate equal to the discount rate.
3. The baseline model is based on fuel price projections from EIA (2012). Fuel prices have fallen significantly since then. For example, the fuel price in 2025 falls from $3.84 (EIA 2012) to $2.74 (EIA 2016). We account for this significant decline in fuel prices by presenting results based on the 2016 AEO.
4. We present results for three discount rates: 5%, 7%, and 13%.

The 2016 Perspective

Having explored the effect of each adjustment separately, we then combine them to determine the joint effect on vehicle sales. The 2016 perspective uses the following data/assumptions that are different from the baseline:

1. ZEV Mandate: turned on
2. Price Premium: now accounts for ZEV and NRC adjustments, but varies
3. Consumer Fuel Price Projections: myopic
4. Consumer Fuel Valuation Period: varies
5. Resale Value: varies
6. Fuel Price: AEO 2016 (reference case; $2.74 in 2025)
7. VMT: NHTSA's updated data from the TAR
8. Financing: auto-loan rate set equal to discount rate (7%)

We explore two variants of price premium and five variants of consumer fuel valuation.

Price Premium

Now accounts for ZEV and NRC adjustments.

1. High price premium uses the NHTSA+NRC(56%)+TAR estimate of ZEV.
2. Low price premium uses the NHTSA+NRC(11%)+DOE estimate of ZEV.
3. Both price premiums use the "medium" consumer valuation of fuel economy described below.

DOE estimate of ZEV is lower than the TAR estimate of ZEV premium.

Consumer Valuation and Resale Value

We consider five alternative specifications for consumer fuel valuation listed in Table VIII.2. Each alternative is run with both the high and low price premium described above.

Table VIII.2. Consumer Valuation of Fuel Savings and Resale Value

Alternative	Consumer Fuel Valuation Period (Years)	Incremental Resale Value
Lower	1	0
Low	3	0
Medium	3	35% of gross premium
High	3	55% of present value of fuel savings from year 6 to 30
Higher	5	100% of present value of fuel savings from year 6 to 30

REMI vs. TCO Price Premium Definition

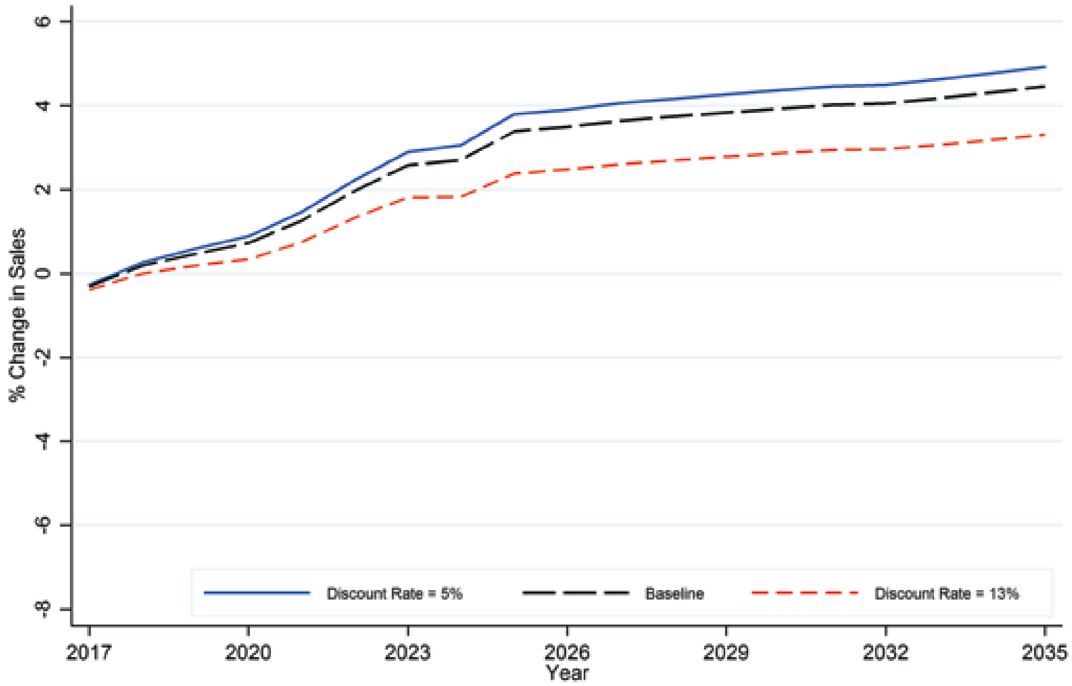
Both REMI and TCO use the terms "2016 perspective high" and "2016 perspective low." Because of differences in their modelling capabilities, each model defines these two terms differently. The differences are illustrated in Table VIII.3.

Table VIII.3. Description of 2016 Perspective Differences between REMI and TCO

	2016 Perspective High		2016 Perspective Low		2016 Perspective COMET	
	REMI	TCO	REMI	TCO	REMI	TCO
Price Premium: NHTSA	Yes	Yes	Yes	Yes	EPA - TAR	EPA - TAR
Price Premium: ZEV	Yes - TAR	Yes - TAR	Yes - DOE	Yes - DOE	Yes - TAR	Yes - TAR
Price Premium: NRC	Yes - High	Yes - High	Yes - Low	Yes - Low		
Consumer Valuation	No	Yes	No	Yes		
Fuel Price	AEO2016	AEO2016	AEO2016	AEO2016		

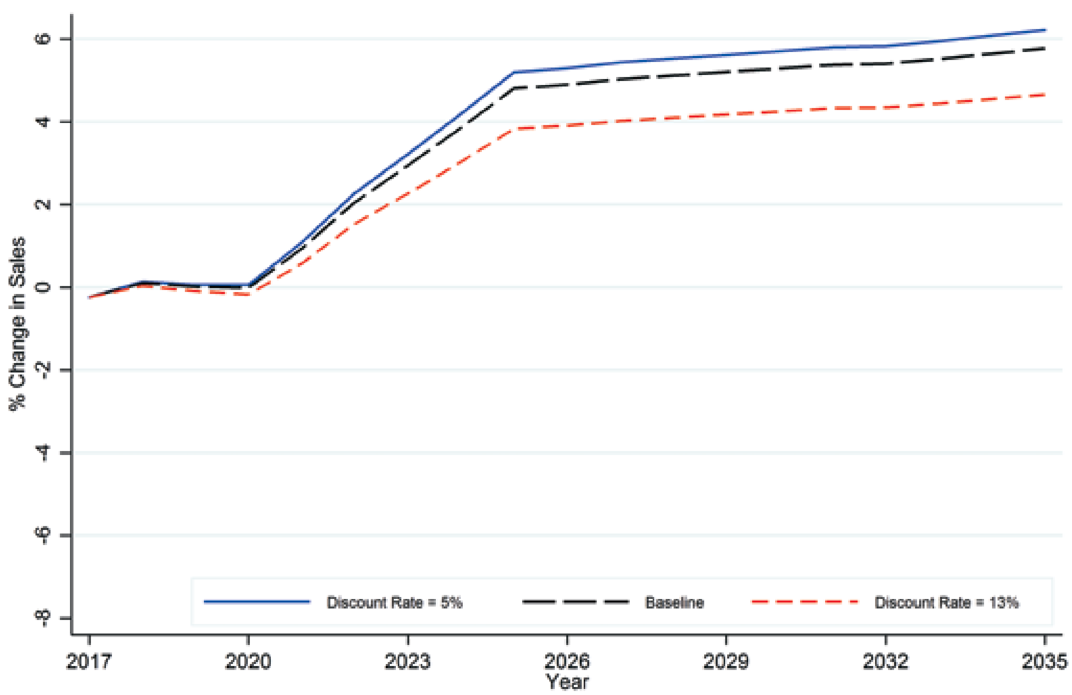
APPENDIX IX:
Results

Figure IX.1. Impact of Regulation on Car Sales, Alternative Discount Rates.



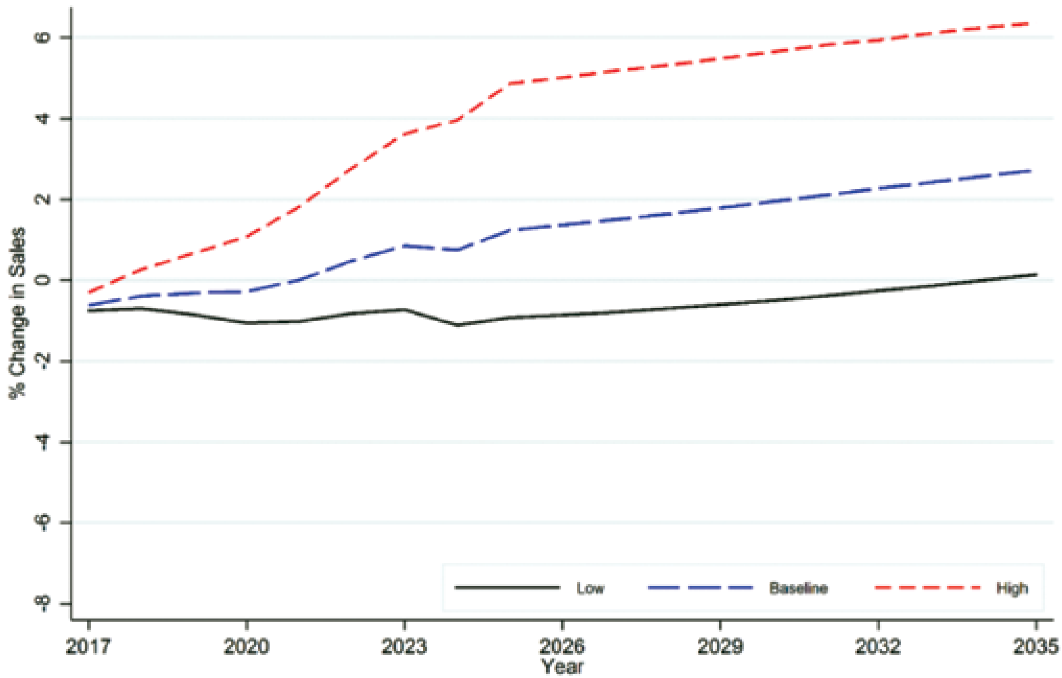
Note: Reported is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about discount rates. *Baseline* reports results using a discount rate of 7%.

Figure IX.2. Impact of Regulation on Truck Sales, Alternative Discount Rates.



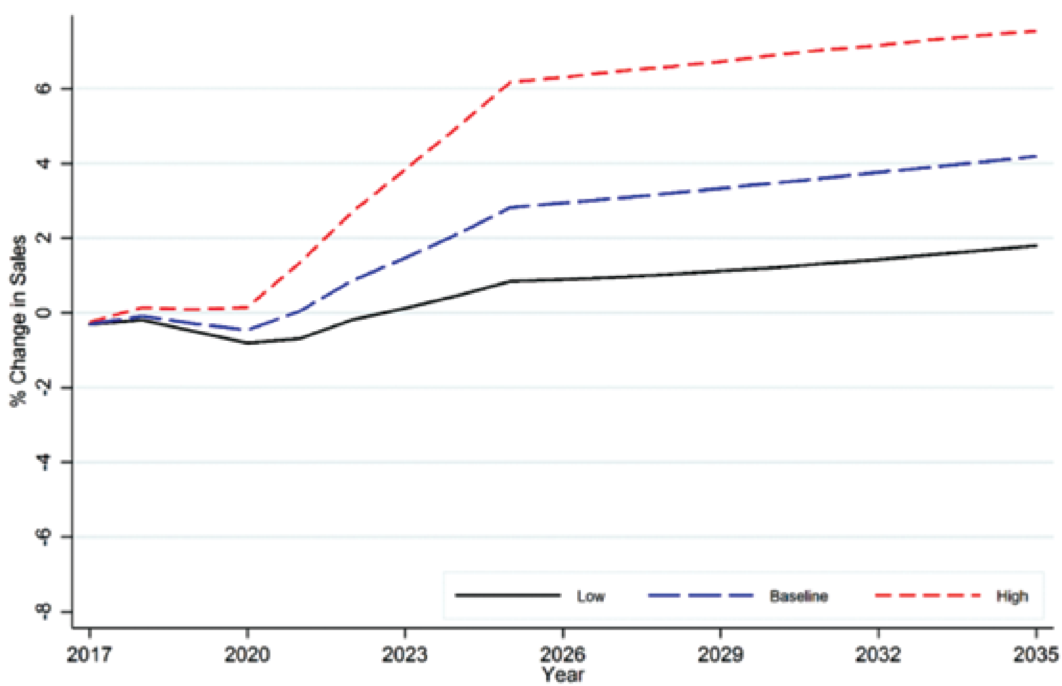
Note: Reported is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about discount rates. *Baseline* reports results using a discount rate of 7%."

Figure IX.3. Impact of Regulation on Car Sales, Alternative Fuel Prices.



*Note***:** Reported is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about fuel prices. *Baseline* reports results using the reference fuel price published in the 2016 annual energy outlook (AEO). *Low* and *High* report the results when we use the AEO 2016 low and high fuel price projections, respectively.

Figure IX.4. Impact of Regulation on Truck Sales, Alternative Fuel Prices.



*Note***:** Reported is the percentage change in vehicle sales due to the regulatory programs based on various assumptions about fuel prices. *Baseline* reports results using the reference fuel price published in the 2016 annual energy outlook (AEO). *Low* and *High* report the results when we use the AEO 2016 low and high fuel price projections, respectively.

References

Addady, Michal. 2016. “Low Gas Prices Are Bad News for Prius Sales.” *Fortune*. September 6. http://fortune.com/2016/09/06/prius-toyota-sales/.

Al-Alawi, Baha M., and Thomas H. Bradley. 2013. “Total Cost of Ownership, Payback, and Consumer Preference Modeling of Plug-in Hybrid Electric Vehicles.” *Applied Energy* 103: 488–506.

Alberini, Anna, Markus Bareit, Massimo Filippini, and Adan L. Martinez-Cruz. 2016. “The Impact of Emissions-Based Taxes on the Retirement of Used and Inefficient Vehicles: The Case of Switzerland,” September. doi:10.2139/ssrn.2836019.

Allcott, Hunt. 2013. “The Welfare Effects of Misperceived Product Costs: Data and Calibrations from the Automobile Market.” *American Economic Journal: Economic Policy* 5 (3): 30–66.

Allcott, Hunt, and Michael Greenstone. 2012. “Is There an Energy Efficiency Gap?” *The Journal of Economic Perspectives: A Journal of the American Economic Association* 26 (1): 3–28.

Allcott, Hunt, and Christopher Knittel. 2017. “Are Consumers Poorly Informed about Fuel Economy? Evidence from Two Experiments.” *Nation Bureau of Economic Research*, January.

Allcott, Hunt, Sendhil Mullainathan, and Dmitry Taubinsky. 2014. “Energy Policy with Externalities and Internalities.” *Journal of Public Economics* 112: 72–88.

Allcott, Hunt, and Nathan Wozny. 2014. “Gasoline Prices, Fuel Economy, and the Energy Paradox.” *The Review of Economics and Statistics* 96 (5): 779–95.

Althaus, Dudley, and Christina Rogers. 2016. “Donald Trump’s Nafta Plan Would Confront Globalized Auto Industry.” *WSJ Online Article*, November 11. http://www.wsj.com/articles/donald-trumps-nafta-plan-would-confront-globalized-auto-industry-1478800848.

American Iron and Steel Institute [AISI]. 2015. “When Lightweighting Matters, Nothing Is as Sure as Steel.” *American Iron and Steel Institute*. https://www.steel.org/Autosteel_org/document-types/enhanced-auto-webpages/texas-webpage.aspx.

Anderson, Soren T., Ryan Kellogg, and James M. Sallee. 2013. “What Do Consumers Believe about Future Gasoline Prices?” *Journal of Environmental Economics and Management* 66 (3): 383–403.

Anderson, Soren T., Ryan Kellogg, James M. Sallee, and Richard T. Curtin. 2011. “Forecasting Gasoline Prices Using Consumer Surveys.” *The American Economic Review* 101 (3). American Economic Association: 110–14.

Anderson, Soren T., Ian W. H. Parry, James M. Sallee, and Carolyn Fischer. 2011. “Automobile Fuel Economy Standards: Impacts, Efficiency, and Alternatives.” *Review of Environmental Economics and Policy* 5 (1): 89–108.

Anderson, Soren T., and James M. Sallee. 2011. “Using Loopholes to Reveal the Marginal Cost of Regulation: The Case of Fuel-Economy Standards.” *The American Economic Review* 101 (4). American Economic Association: 1375–1409.

Appelbaum, Binyamin. 2015. “When Gas Becomes Cheaper, Americans Buy More Expensive Gas.” *The New York Times*, October 19. http://www.nytimes.com/2015/10/20/upshot/when-gas-becomes-cheaper-americans-buy-more-expensive-gas.html.

———. 2016. “This Time, Cheaper Oil Does Little for the U.S. Economy.” *The New York Times*, January 21. http://www.nytimes.com/2016/01/22/business/energy-environment/this-time-cheaper-oil-does-little-for-the-us-economy.html.

Ariely, Dan. 2008. “Eyes Off the Price.” *The New York Times*, July 19. http://www.nytimes.com/2008/07/19/opinion/19ariely.html.

Arora, Vipin. 2015. “Oil Prices and the U.S. Economy: Where Is the Boom?” Economics Discussion Papers 2015-48. Kiel Institute for the World Economy. http://www.economics-ejournal.org/economics/discussionpapers/2015-48/file.

Atiyeh, Clifford. 2015. “The Tax Man Cometh: These 10 States Charge Extra Fees for Electric Cars.” *Car and Driver*. December 3. http://blog.caranddriver.com/the-tax-man-cometh-these-10-states-charge-extra-fees-for-electric-cars/.

Austin, David, and Terry Dinan. 2005. "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes." *Journal of Environmental Economics and Management* 50 (3): 562–82.

Auto Alliance and Global Automakers. Letter to Environmental Protection Agency. 2016. "Petition for Direct Final Rule with Regard to Aspects of the Corporate Average Fuel Economy Program and the Greenhouse Gas Program," June 20. https://www.epa.gov/sites/production/files/2016-09/documents/petition_to_epa_from_auto_alliance_and_global_automakers.pdf.

Axelgeeks. 2010. "2010 Toyota RAV4 vs Ford Escape Hybrid - Cars Comparison." http://cars.axlegeeks.com/compare/26398-33558/2010-Toyota-RAV4-vs-2010-Ford-Escape-Hybrid.

Axsen, Jonn, and Kenneth S. Kurani. 2008. "The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts." UCD-ITS-RR-08-22. UCD-ITS-RR-08-22. Institute of Transportation Studies. http://dx.doi.org/.

Baker, Erin, Haewon Chon, and Jeffrey Keisler. 2010. "Battery Technology for Electric and Hybrid Vehicles: Expert Views about Prospects for Advancement." *Technological Forecasting and Social Change* 77 (7): 1139–46.

Bandivadekar, Anup, Lynette Cheah, Christopher Evans, Tiffany Groode, John Heywood, Emmanuel Kasseris, Matthew Kromer, and Malcolm Weiss. 2008. "Reducing the Fuel Use and Greenhouse Gas Emissions of the US Vehicle Fleet." *Energy Policy* 36 (7): 2754–60.

Baum, Alan, and Daniel Luria. 2016. "Economic Implications of the Current National Program v. a Weakened National Program in 2022-2025 for Detroit Three Automakers and Tier One Suppliers." *Ceres*. June 27. http://ceres.org/files/analyst-brief-economic-effects-on-us-automakers-and-suppliers.

———. 2010. "Driving Growth: How Clean Cars and Climate Policy Can Create Jobs." Natural Resources Defense Council (NRDC), United Auto Workers (UAW), Center for American Progress (CAP).

Baum and Associates. 2016. "Preview-of-Supplying-Ingenuity-II-vFINAL.pdf." Blue Green Alliance. https://www.bluegreenalliance.org/wp-content/uploads/2016/12/Preview-of-Supplying-Ingenuity-II-vFINAL.pdf.

Becker, Thomas A., Ikhlaq Sidhu, and Burghardt Tenderich. 2009. "Electric Vehicles in the United States: A New Model with Forecasts to 2030." *Center for Entrepreneurship and Technology, University of California, Berkeley* 24. http://www.ehcar.net/library/rapport/rapport051.pdf.

Beene, Ryan. 2015a. "How U.S. Chickens Led to Japanese Truck Plants." *Automotive News*. http://www.autonews.com/article/20150629/OEM/306299959/how-u.s.-chickens-led-to-japanese-truck-plants.

———. 2015b. "Audi's A3 E-Tron to Pave Way for Electrified Vehicle Push." *Automotive News*. November 1. http://www.autonews.com/article/20151101/OEM05/311029960/audis-a3-e-tron-to-pave-way-for-electrified-vehicle-push.

———. 2016a. "EPA Ponders Post-2025 Regulation." *Automotive News*. January 18. http://www.autonews.com/article/20160118/OEM11/301189971/epa-ponders-post-2025-regulation.

———. 2016b. "Industry Blindsided as CAFE Fines Jump." *Automotive News*. July 16. http://www.autonews.com/article/20160716/OEM11/307189981/industry-blindsided-as-cafe-fines-jump.

Bennett, Jeff, and John D. Stoll. 2015. "November Car Sales Drive Toward Record." *Wall Street Journal*, December 1. http://www.wsj.com/articles/fiat-chrysler-november-sales-climb-3-1448974855.

Bento, Antonio M., Shanjun Li, and Kevin Roth. 2012. "Is There an Energy Paradox in Fuel Economy? A Note on the Role of Consumer Heterogeneity and Sorting Bias." *Economics Letters* 115 (1): 44–48.

Beresteanu, Arie, and Shanjun Li. 2011. "Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles in the United States." *International Economic Review* 52 (1). Department of Economics, University of Pennsylvania and Osaka University Institute of Social and Economic Research Association: 161–82.

Berman, Brad. 2011. "Ford Says Goodbye to the Escape Hybrid." *HybridCars.com*. October 6. http://www.hybridcars.com/ford-says-goodbye-escape-hybrid-31305/.

———. 2012. "Slow Uptake on Green Carpool Stickers for Plug-in Hybrids." *PluginCars.com*. http://www.plugincars.com/slow-uptake-green-carpool-stickers-plug-hybrids-123901.html.

Bezdek, Roger H., and Robert M. Wendling. 2005. “Potential Long-Term Impacts of Changes in US Vehicle Fuel Efficiency Standards.” *Energy Policy* 33 (3): 407–19.

Bienenfeld, R. 2016. “Advanced Powertrains 2025 & Beyond – What’s Driving Us?” presented at the CAR Management Briefing Seminars, September.

Blake, Mike. 2011. “U.S. Gas Prices Hit $4 a Gallon, but May Retreat.” *Reuters*. May 8. http://www.reuters.com/article/us-energy-gasoline-retail-idUSTRE7472DI20110508.

BlueGreen Alliance. 2016. “Combating Climate Change 426,000 Pickup Trucks at a Time.” BlueGreen Alliance. https://www.bluegreenalliance.org/wp-content/uploads/2016/08/BGA_FordF150s_FINAL.pdf.

Blumenthal, Eli. 2016. “Drivers Are Wasting Their Money on Premium Gas.” *USA Today*, September 20. http://www.usatoday.com/story/money/cars/2016/09/20/buying-premium-gas-when-you-only-need-regular-youre-wasting-your-money-says-aaa/90726998/.

Bomgardner, Melody M. 2016. “Cellulosic Ethanol Comes into View | April 11, 2016 Issue - Vol. 94 Issue 15 | Chemical & Engineering News.” *Chemical & Engineering News*. April 11. http://cen.acs.org/articles/94/i15/Cellulosic-ethanol-comes-view.html?type=paidArticleContent.

Bond, Vince, Jr., and Nick Bunkley. 2013. “EPA Engineer Expects More Audits of Mileage Claims.” *Automotive News*. February 18. http://www.autonews.com/article/20130218/OEM01/302189984/epa-engineer-expects-more-audits-of-mileage-claims.

Boston Consulting Group. 2010. “Batteries for E-Cars: Challenges, Opportunities, and the Outlook for 2020.” http://www.bcg.com/documents/file36615.pdf.

Boston, William. 2015. “Auto Makers Enter Untested Waters as Technology Takes Bigger Role.” *Wall Street Journal*, September 13. http://www.wsj.com/articles/auto-makers-enter-untested-waters-as-technology-takes-bigger-role-1442050383.

———. 2016. “Volkswagen to Boost Electric Vehicles, Pursue Self-Driving Cars.” *WSJ Online Article*. http://www.wsj.com/articles/volkswagen-to-boost-electric-vehicles-pursue-self-driving-cars-1466015734.

Boudette, Neal E. 2016. “Latecomers to Mexico Face Fight for Resources.” *Automotive News*. January 23. http://www.autonews.com/article/20160123/OEM10/301259990/latecomers-to-mexico-face-fight-for-resources.

Brown, Bruce, Michelle Drew, Candan Erenguc, Robert Hill, Steve Schmith, and Bharath Gangula. 2014. “2014 Global Automotive Consumer Study: Exploring Consumers’ Mobility Choices and Transportation Decisions.” Deloitte Development LLC. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-auto-global-automotive-consumer-study-100914.pdf.

Brown, Stephen, David Pyke, and Paul Steenhof. 2010. “Electric Vehicles: The Role and Importance of Standards in an Emerging Market.” *Energy Policy* 38 (7). Elsevier: 3797–3806.

Bruyn, Sander de, Linda Brinke, Bettina Kampman, and Marnix Koopman. 2012a. “Literature Review on Employment Impacts of GHG Reduction Policies for Transport.” CE Delft. https://www.transportenvironment.org/sites/te/files/publications/CE%20Delft%20-%20Literature%20review%20on%20employment%20impacts%20of%20GHG%20reduction%20policies%20for%20transport%20FINAL%20(3).pdf.

Bühler, Franziska, Peter Cocron, Isabel Neumann, Thomas Franke, and Josef F. Krems. 2014. “Is EV Experience Related to EV Acceptance? Results from a German Field Study.” *Transportation Research. Part F, Traffic Psychology and Behaviour* 25, Part A (July): 34–49.

Bunkley, Nick. 2016. “The Family Car Is in Free Fall.” *Automotive News*. http://www.autonews.com/article/20160905/RETAIL01/309059951/the-family-car-is-in-free-fall.

Bureau of Economic Analysis [BEA]. 2009. “Concepts and Methods of the U.S. Input-Output Accounts.” U.S. Department of Commerce. https://www.bea.gov/papers/pdf/iomanual_092906.pdf.

———. 2016. “Interactive Access to Industry Economic Accounts Data: GDP by Industry.” https://www.bea.gov/iTable/index_industry_gdpIndy.cfm.

Bureau of Labor Statistics [BLS]. 2015. "Employment in Motor Vehicle Parts and Manufacturing." http://data.bls.gov/timeseries/CES3133600101?data_tool=XGtable.

———. 2017. "Green Goods and Services." https://www.bls.gov/ggs/.

Burke, Katie. 2016. "Tesla Owners Plagued by Service Delays." *Automotive News*. November 13. http://www.autonews.com/article/20161113/RETAIL05/311149995/tesla-owners-plagued-by-service-delays.

Burroughs, Amy. 2013. "In Globalization Age, What Does 'Made in America' Mean? – Kogod Now." *Kogod Biz - American University*. March 18. http://kogodnow.com/2013/03/in-globalization-age-what-does-made-in-america-mean/.

Burtraw, Dallas. 2016. "Why California's Cap-and-Trade Program Works." *Resources for the Future*. September 14. http://www.rff.org/research/publications/commentary-why-california-s-cap-and-trade-program-works.

Busch, Chris, John Laitner, Rob McCulloch, and Ivana Stosic. 2012. "Gearing Up: Smart Standards Create Good Jobs Building Cleaner Cars." BlueGreen Alliance. https://www.bluegreenalliance.org/wp-content/uploads/2016/08/062812-GearingUp_Final.pdf.

Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer. 2013. "Are Consumers Myopic? Evidence from New and Used Car Purchases." *The American Economic Review* 103 (1): 220–56.

Cahill, Eric, and Dan Sperling. 2016. "ITS – The Future of Electric Vehicles Part 1: Car Dealers Hold the Key." https://its.ucdavis.edu/blog-post/the-future-of-electric-vehicles-part-1-car-dealers-hold-the-key/.

California Air Resources Board [CARB]. 2013. "Final Regulation Order Section 1962.2. Zero Emission Vehicle Standards for 2018 and Subsequent Model Year Passenger Car and Light Duty Trucks and Medium Duty Vehicles." https://www.arb.ca.gov/msprog/zevprog/zevregs/1962.2_Clean.pdf.

———. 2011a. "2012 Proposed Amendments to the California Zero Emission Vehicle Program Regulations." https://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf.

———. 2011b. "2012 Proposed Amendments to the California Zero Emission Vehicle Program Regulations - Appendix C - Economic Analysis Inputs."

———. 2012a. "The Zero Emission Vehicle (ZEV) Regulation." https://www.arb.ca.gov/msprog/zevprog/factsheets/general_zev_2_2012.pdf.

———. 2012b. "Zero-Emission Vehicle Standards for 2018 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles." 1962.2. https://www.arb.ca.gov/regact/2012/zev2012/fro2rev.pdf.

———. 2012c. "Updated Informative Digest - Zero Emission Vehicle Regulation Amendments." https://www.arb.ca.gov/regact/2012/zev2012/zevuid.pdf.

———. 2014. "Staff Report: Initial Statement of Reasons for Rulemaking - Proposed 2014 Amendments to the Zero Emission Vehicle Regulation." https://www.arb.ca.gov/regact/2014/zev2014/zev14isor.pdf.

———. 2015. "2015 Update to the Board: Advanced Clean Cars Program Midterm Review." https://www.arb.ca.gov/board/books/2015/102215/15-8-7pres.pdf.

———. 2016. "2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development." https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.

California Energy Commission. 2016. "Tracking Progress - Zero-Emission Vehicles and Infrastructure." http://www.energy.ca.gov/renewables/tracking_progress/documents/electric_vehicle.pdf.

Cames, Michel, and Eckard Helmers. 2013. "Critical Evaluation of the European Diesel Car Boom - Global Comparison, Environmental Effects and Various National Strategies." *Environmental Sciences Europe* 25 (1): 1–22.

Canadian Black Books. 2016. "Canadian Black Book | Used Cars | New Cars | Cars For Sale." http://www.canadianblackbook.com/.

Canis, Bill. 2013. "Battery Manufacturing for Hybrid and Electric Vehicles: Policy Issues." R41709. Congressional Research Service, Library of Congress. https://fas.org/sgp/crs/misc/R41709.pdf.

Carley, Sanya, Natalie Messer Betts, and John D. Graham. 2011. "Innovation in the Auto Industry: The Role of the U.S. Environmental Protection Agency." *Duke Environmental Law & Policy Forum* 21: 367–99.

Carley, Sanya, Rachel M. Krause, Bradley W. Lane, and John D. Graham. 2013. "Intent to Purchase a Plug-in Electric Vehicle: A Survey of Early Impressions in Large US Cites." *Transportation Research Part D: Transport and Environment* 18: 39–45.

Carrns, Ann. 2013. "Tips for Buying and Servicing a Used Hybrid Car." *The New York Times*, May 30. https://bucks.blogs.nytimes.com/2013/05/30/tips-for-buying-a-used-hybrid-car/.

Carstensen, Fred, William Lott, Stan McMillen, Bobur Alimov, Na Li Dawson, and Tapas Ray. 2000. "The Economic Impact of the Mashantucket Pequot Tribal Nation Operations on Connecticut." *Storrs: Connecticut Center for Economic Analysis, University of Connecticut*. ccea.uconn.edu. http://www.ccea.uconn.edu/studies/Mashantucket%20Final%20Report.PDF.

Center for Automotive Research [CAR]. 2011. "The U.S. Automotive Market and Industry in 2025."

———. 2015. "Contribution of the Automotive Industry to the Economies of All Fifty States and the United States." http://www.cargroup.org/?module=Publications&event=View&pubID=113.

———. 2016. "The Effects of the 2025 EPA/NHTSA GHG/Fuel Economy Mandates on the U.S. Economy."

Chandra, Ambarish, Sumeet Gulati, and Milind Kandlikar. 2010. "Green Drivers or Free Riders? An Analysis of Tax Rebates for Hybrid Vehicles." *Journal of Environmental Economics and Management* 60 (2): 78–93.

Chappell, Lindsay. 2016. "Test for Tesla: Luring Suppliers to California." *Automotive News*. http://www.autonews.com/article/20160801/OEM10/308019985/test-for-tesla%3A-luring-suppliers-to-calif.

Christensen, Clayton M., Michael E. Raynor, and Rory McDonald. 2015. "What Is Disruptive Innovation?" *Harvard Business Review*. December. https://hbr.org/2015/12/what-is-disruptive-innovation.

Chung, Donald, Emma Elgqvist, and Shriram Santhanagopalan. 2015. "Automotive Lithium-Ion Battery Supply Chain and U.S. Competitiveness Considerations." June. doi:NREL/PR-6A50-63354.

Clark, Pilita, and Peter Campbell. 2016. "Motor Industry: Pressure on the Pump." *Financial Times*. August 30. https://www.ft.com/content/31d68af8-6e0a-11e6-9ac1-1055824ca907.

Clark, Pilita, and Andy Sharman. 2015. "VW Scandal Set to Choke Diesel Car Industry." *Financial Times*. September 22. http://www.ft.com/cms/s/0/a3d1041a-6138-11e5-9846-de406ccb37f2.html#axzz3yNIvkxCd.

Clark-Sutton, Kyle, Saba Siddiki, Sanya Carley, Celeste Wanner, John Rupp, and John D. Graham. 2016. "Plug-in Electric Vehicle Readiness: Rating Cities in the United States." *Electricity Journal* 29 (1): 30–40.

Clean Vehicle Rebate Project [CVRP]. 2012. "FAQs." *Clean Vehicle Rebate Project*. https://cleanvehiclerebate.org/eng/faqs.

Clegern, David. 2012. "California Air Resources Board Approves Advanced Clean Car Rules," January 27. https://www.arb.ca.gov/newsrel/newsrelease.php?id=282.

Clinton, Bentley, Austin Brown, Carolyn Davidson, and Daniel Steinberg. 2015. "Impact of Direct Financial Incentives in the Emerging Battery Electric Vehicle Market: A Preliminary Analysis." http://www.nrel.gov/docs/fy15osti/63263.pdf.

Cobb, by Jeff. 2017. "December 2016 Dashboard - HybridCars.com." *HybridCars.com*. January 5. http://www.hybridcars.com/december-2016-dashboard/.

Coglianese, Cary, and Christopher Carrigan. 2013. "1. The Jobs and Regulation Debate." In *Does Regulation Kill Jobs?*, 1–30. University of Pennsylvania Press.

Cole, Jay. 2017. "December 2016 Plug-In Electric Vehicle Sales Report Card." http://insideevs.com/december-2016-plug-electric-vehicle-sales-report-card/.

Colias, Mike. 2015. "Cadillac's Plug-in Play: Hybrids First, Then EV." *Automotive News*. November 23. http://www.autonews.com/article/20151123/OEM04/311239998/cadillacs-plug-in-play%3A-hybrids-first-then-ev.

———. 2016a. "Chevy Opens an Aluminum Can on Ford." *Automotive News*. June 13. http://www.autonews.com/article/20160613/RETAIL03/306139960/chevy-opens-an-aluminum-can-on-ford.

———. 2016b. "GM to Add More Diesel-Powered Cars." *Wall Street Journal*, September 24. http://www.wsj.com/articles/gm-to-add-more-diesel-powered-cars-1474709401.

Colias, Mike, Adrienne Roberts, and Christine Rogers. 2016. "Wary Automakers Tap the Breaks. Wall Street Journal." *Wall Street Journal*, December 22.

Commission for Environmental Cooperation [CEC]. 2015. "Environmentally Sound Management of End-of-Life Batteries from Electric-Drive Vehicles in North America." http://www3.cec.org/islandora/en/item/11637-environmentally-sound-management-end-life-batteries-from-electric-drive-vehicles-en.pdf.

Congressional Budget Office [CBO]. 2004. "Fuel Economy Standards Versus a Gasoline Tax." https://www.ftc.gov/sites/default/files/documents/public_events/Energy%20Markets%20in%20the%2021st%20Century%3A%20Competition%20Policy%20in%20Perspective/austin.pdf.

———. 2012. "Effects of Federal Tax Credits for the Purchase of Electric Vehicles." https://www.cbo.gov/publication/43576.

Conoscenti, Christopher L. 2011. "Macroeconomic Impacts of the Domestic Oil and Gas Industry." 5. National Petroleum Council [NPC]. http://www.npc.org/prudent_development-topic_papers/5-1_macroeconomic_impacts_of%20oil_and_gas_industry_paper.pdf.

Consumers Union. 2016. "Hybrid/EV Buying Guide." *Consumer Reports*. August. http://www.consumerreports.org/cro/cars/hybrids-evs/buying-guide.htm.

Covert, Thomas, Michael Greenstone, and Christopher R. Knittel. 2016. "Will We Ever Stop Using Fossil Fuels?" *The Journal of Economic Perspectives: A Journal of the American Economic Association* 30 (1): 117–38.

Cox, Jeff. 2015. "Falling Gas Prices Not Doing Much for the Economy." *Nightly Business Report*. http://nbr.com/2015/07/22/falling-gas-prices-not-doing-much-for-the-economy/.

Crandall, Robert W. 1992. "Policy Watch: Corporate Average Fuel Economy Standards." *The Journal of Economic Perspectives: A Journal of the American Economic Association* 6 (2): 171–80.

Crandall, Robert W., Howard K. Gruenspecht, Theodore E. Keeler, and Lester B. Lave. 1986. *Regulating the Automobile*. Brookings Institution.

Curtin, Matthew. 2009. "Europe's Small-Car Blues." *WSJ*. wsj.com. August 7. http://www.wsj.com/articles/SB124956448479510955.

Cuthbertson, Anthony. 2016. "Renault Plans $8,000 Electric Car for 2018." *Newsweek*. November 9. http://www.newsweek.com/renault-plans-8000-electric-car-2018-519044.

Cutter, Eric. 2015. "Maximizing EV Benefits." January 21. http://policyinstitute.ucdavis.edu/files/E3-UC-Davis-Policy-Forum-v2.pdf.

———. 2016. "Transportation Electrification Cost-Benefit Analysis." presented at the CPUC SB 350 Workshop, April 29. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjl5uL1z-XQAhVB-2MKHSwxBiMQFggaMAA&url=http%3A%2F%2Fwww.cpuc.ca.gov%2FWorkArea%2FDownloadAsset.aspx%3Fid%3D11290&usg=AFQjCNHZP6Mcu3cg8167lRD7wPXcDO20OQ&bvm=bv.140915558,bs.1,d.cGc.

DeBord, Matthew, and Peter Rudegeair. 2014. "US Auto Loans Are Surging As Banks Boost Used Car Financing." *Business Insider*. September 3. http://www.businessinsider.com/r-us-consumers-turn-to-auto-loans-at-a-record-rate-2014-9.

Deller, S. C. 1995. "Economic Impact of Retirement Migration." *Economic Development Quarterly*. edq.sagepub.com. http://edq.sagepub.com/content/9/1/25.short.

DeMorro, Christopher. 2015a. "Another $2 Million For Massachusetts EV Incentive Program." *EV Obsession*. April 8. http://evobsession.com/another-2-million-for-massachusetts-ev-incentive-program/.

———. 2015b. "Connecticut Offering Up To $3,000 Rebate To EV, PHEV, And FCV Buyers." *EV Obsession*. May 21. http://evobsession.com/connecticut-offering-up-to-3000-rebate-to-ev-phev-and-fcv-buyers/.

Department of Energy [DOE]. 2013. "U.S. Battery R&D Progress and Plans." David Howell, Team Leader, Hubrid & Electric Vehicles R&D, Vehicle Technologies Office. http://energy.gov/sites/prod/files/2014/03/f13/es000_howell_2013_o.pdf.

———. 2016. "Alternative Fuels Data Center: Vehicle Search." http://www.afdc.energy.gov/vehicles/search/results/?view_ mode=grid&search_field=vehicle&search_dir=desc&per_page=8&current=true&ajax_count=60&fuel_id=11&category_id=27,25,29,9,&all_manufacturers=y.

———. 2017a. "Alternative Fuels Data Center: Maps and Data." http://www.afdc.energy.gov/data/.

———. 2017b. "Ethanol." *Fuel Economy*. https://www.fueleconomy.gov/feg/ethanol.shtml.

Department of Transportation [DOT]. 2015. "Table 1-19: Sales of Hybrid Vehicles in the United States." *Bureau of Transportation Statistics*. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_19.html.

Dial, Victor. 2011. "Ou Est Le 'Cash for Clunkers'?" *Wall Street Journal*, January 7. http://www.wsj.com/articles/SB10001424052748704405704576064293103283366.

Diamond, David. 2009. "The Impact of Government Incentives for Hybrid-Electric Vehicles: Evidence from US States." *Energy Policy* 37 (3). Elsevier: 972–83.

Diesel Technology Forum. 2017. "What Is SCR? | Diesel Technology Forum." *Http://www.dieselforum.org*. http://www.dieselforum.org/about-clean-diesel/what-is-scr.

Dolan, Matthew, and John Murphy. 2009. "Nissan, Ford Plan Electric Push Aided by U.S.; Demand Is Uncertain." *Wall Street Journal*. wsj.com. June 24. http://www.wsj.com/articles/SB124573130607640647.

Drake, D. A. 1995. "Technology, Economics, and the ZEV Mandate: A Vehicle Manufacturer's Perspective." In *Transportation and Energy: Strategies for a Sustainable Transportation System*, edited by D. Sperling and S. A. Shaheen, 243–54. Washington, DC: American Council for an Energy Efficient Economy.

Draper, Matt, Ernesto Rodriguez, Phil Kaminsky, Ikhlaq Sidhu, and Burghardt Tenderich. 2008. "Economic Impact of Electric Vehicle Adoption in the United States." 2008.3.v.1. Global Venture Lab, University of California-Berkeley. https://ikhlaqsidhu.files.wordpress.com/2010/03/nr_electric_vehicle_economics_3gvlv1-1_2008.pdf.

DuBois, Frank. 2016. "2016 Kogod Made in America Auto Index." *Kogod School of Business*. http://kogodbusiness.com/reports/auto-index/.

Duleep, K. G. 2016. "Complying with the CAFE Standards: Will It Be More Difficult than Predicted?" *Resources for the Future*. February 11. http://www.rff.org/blog/2016/complying-cafe-standards-will-it-be-more-difficult-predicted.

Dumortier, Jerome, Matthew W. Kent, and Seth B. Payton. 2016. "Plug-in Vehicles and the Future of Road Infrastructure Funding in the United States." *Energy Policy* 95 (August): 187–95.

Dumortier, Jerome, Saba Siddiki, Sanya Carley, Joshua Cisney, Rachel M. Krause, Bradley W. Lane, John A. Rupp, and John D. Graham. 2015. "Effects of Providing Total Cost of Ownership Information on Consumers' Intent to Purchase a Hybrid or Plug-in Electric Vehicle." *Transportation Research Part A: Policy and Practice* 72: 71–86.

Dziczek, Kristin, Yen Chen, Bernard Swiecki, Michael Schultz, Deb Menk, and Juliana Patterson. 2016. "Contribution of Toyota Motor North America to the Economies of Nineteen States and the United States in 2015." Center for Automotive Research [CAR]. http://www.cargroup.org/assets/files/toyota_economic__contribution_to_us_2016_draft.pdf.

Dziczek, Kristin, Brett Smith, Yen Chen, Michael Schultz, and David Andrea. 2016. "The Economic Implications of Potential NHTSA and EPA Regulatory Revisions on U.S. Light Truck Sales and Manufacturing." Center for Automotive Research.

Dziczek, Kristin, Bernard Swiecki, Yen Chen, Valerie Brugeman, Michael Schultz, and David Andrea. 2017. "NAFTA Briefing: Trade Benefits to the Automotive Industry and Potential Consequences of Withdrawal from the Agreement." Center for Automotive Research.

Edelstein, Paul, and Lutz Kilian. 2009. "How Sensitive Are Consumer Expenditures to Retail Energy Prices?" *Journal of Monetary Economics* 56 (6): 766–79.

Edelstein, Stephen. 2015. "California Ends Electric-Car Rebates For Wealthy Buyers, Boosts Them For Poorest." *Green Car Reports*. July 21. http://www.greencarreports.com/news/1098988_california-ends-electric-car-rebates-for-wealthiest-buyers-boosts-them-for-poorest.

Edmunds. 2016a. "2016 Ford C-Max Hybrid Wagon Review." *Edmunds*. http://www.edmunds.com/ford/c-max-hybrid/2016/wagon/review/.

———. 2016b. “2016 Toyota RAV4 Hybrid Review & Ratings | Edmunds.” *Edmunds*. https://www.edmunds.com/toyota/rav4-hybrid/2016/review/.

Egbue, Ona, and Suzanna Long. 2012. “Barriers to Widespread Adoption of Electric Vehicles: An Analysis of Consumer Attitudes and Perceptions.” *Energy Policy* 48: 717–29.

Electric Drive Transportation Association [EDTA]. 2016. “Electric Drive Sales Dashboard.” http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952.

Elgowainy, Amgad, Jeongwoo Han, Jacob Ward, Fred Joseck, David Gohlke, Alicia Lindauer, Todd Ramsden, et al. 2016. “Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies.” Department of Energy. https://greet.es.anl.gov/publication-c2g-2016-report.

Energy + Environmental Economics [E3]. 2014. “California Transportation Electrification Assessment - Phase 2: Grid Impacts.” Energy + Environmental Economics. https://www.researchgate.net/profile/Eric_Cutter/publication/267694861_California_Transportation_Electrification_Assessment_Phase_2_GridImpacts/links/5457f67a0cf26d5090ab55a8.pdf?inViewer=0&pdfJsDownload=0&origin=publication_detail.

Energy Information Administration [EIA]. 2012. “Annual Energy Outlook 2012 with Projections to 2035.” DOE/EIA-0383(2012). http://www.eia.gov/outlooks/aeo/pdf/0383(2012).pdf.

———. 2014. “Annual Energy Outlook 2014 with Projections to 2040.” DOE/EIA-0383(2014). http://www.eia.gov/outlooks/aeo/pdf/0383(2014).pdf.

———. 2015a. “Annual Energy Outlook Retrospective Review: Evaluation of 2014 and Prior Reference Case Projections.”

———. 2015b. “Annual Energy Outlook 2015 with Projections to 2040.” DOE/EIA-0383(2015).

———. 2016. “Annual Energy Outlook 2016 with Projections to 2040.” DOE/EIA-0383(2016). http://www.eia.gov/outlooks/aeo/.

Environmental Protection Agency [EPA]. 2009a. “Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers.” EPA-420-R-09-003. Prepared for EPA by RTI International.

———. 2009b. “Light-Duty Technology Cost Analysis Pilot Study.” EPA-420-R-09-020. Prepared for EPA by FEV, Inc. .

———. 2011. “Light-Duty Vehicle Technology Cost Analysis, Advanced 8-Speed Transmissions.” EPA-420-R-11-022. Prepared for EPA by FEV, Inc.

———. 2012a. “Regulatory Impact Analysis: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.” EPA-420-R-12-016.

———. 2012b. “EPA Decision to Grant California’s Request for Waiver of Preemption for Its Advanced Clean Car Program.” Regulatory Announcement. U.S. Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100FGS0.PDF?Dockey=P100FGS0.PDF.

———. 2013. “[EPA] California State Motor Vehicle Pollution Control Standards; Notice of Decision Granting a Waiver of Clean Air Act Preemption for California’s Advanced Clean Car Program and a Within the Scope Confirmation for California’s Zero Emission Vehicle Amendments for 2017 and Earlier Model Years.” FRL–9768–1. Vol. 78(6). Environmental Protection Agency. https://www.gpo.gov/fdsys/pkg/FR-2013-01-09/pdf/2013-00181.pdf.

———. 2014. “MPG: Label Values vs. Corporate Average Fuel Economy (CAFE) Values.”

———. 2015. “EPA Decision Document: Off-Cycle Credits for Fiat Chrysler Automobiles, Ford Motor Company and General Motors Corporation.” EPA-420-R-15-014.

———. 2016a. “Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation: Technical Support Document.” EPA-420-R-16-021. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100Q3L4.pdf.

———. 2016b. “Vehicle Emissions California Waivers and Authorizations.” *U.S. Environmental Protection Agency*. https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations.

———. 2016c. “Greenhouse Gas Emission Standards for Light Duty Vehicles: Manufacturer Performance Report for the 2015 Model Year.” EPA-420-R-16-014. https://www.epa.gov/sites/production/files/2016-11/documents/420r16014.pdf.

———. 2016d. “Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2016.” EPA-420-R-16-010. https://www.epa.gov/sites/production/files/2016-11/documents/420r16010.pdf.

Environmental Protection Agency [EPA], National Highway Traffic Safety Administration [NHTSA]. 2012. “Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.” EPA-420-R-12-901.

Fan, Wei, Frederick Treyz, and George Treyz. 2000. “An Evolutionary New Economic Geography Model.” *Journal of Regional Science* 40 (4). Blackwell Publishers Inc: 671–95.

Farrell, Diana, and Fiona Greig. 2015. “How Falling Gas Prices Fuel the Consumer: Evidence from 25 Million People.” JPMorgan Chase & Co. Institute.

Faucon, Benoît, and Summer Said. 2015. “OPEC Sees Oil Price Below $100 a Barrel in the Next Decade.” *WSJ Online Article*, May 12. http://www.wsj.com/articles/opec-sees-oil-price-below-100-a-barrel-in-the-next-decade-1431347035.

Federal Highway Administration. 2011. “Summary of Travel Trends.” FHWA-PL-11-022. Department of Transportation. http://nhts.ornl.gov/2009/pub/stt.pdf.

Fehrenbacher, Katie. 2016a. “Tesla’s Model 3 Reservations Rise to Almost 400,000.” *Fortune*. April 15. http://fortune.com/2016/04/15/tesla-model-3-reservations-400000/.

———. 2016b. “Elon Musk: Tesla Was In ‘Production Hell’ This Year.” *Fortune*. August 4. http://fortune.com/2016/08/03/elon-musk-production-hell/.

Felgenhauer, Markus F., Matthew A. Pellow, Sally M. Benson, and Thomas Hamacher. 2016. “Evaluating Co-Benefits of Battery and Fuel Cell Vehicles in a Community in California.” *Energy* 114 (November): 360–68.

Fergusson, Ian F. 2011. “United States-Canada Trade and Economic Relationship: Prospects and Challenges.” 7-5700. Congressional Research Service [CRS]. https://books.google.com/. http://books.goole.com/books?hl=en&lr=&id=MgCHKMo4D-mgC&oi=fnd&pg=PA75&equ=United+States+Canda+Trad+economic+Relationship+Prospects+Challenges+Fergusson&ots=kTZTUT-TjmW&sig=yGGwJRG9Okus-sp2X0prP–QaDqs.

Ferris, Ann E., and Al Mcgartland. 2013. “9. A Research Agenda for Improving the Treatment of Employment Impacts in Regulatory Impact Analysis.” In *Does Regulation Kill Jobs?*, 170–89. University of Pennsylvania Press.

Figenbaum, Erik, Nils Fearnley, Paul Pfaffenbichler, Randi Hjorthol, Marika Kolbenstvedt, Reinhard Jellinek, Bettina Emmerling, et al. 2015. “Increasing the Competitiveness of E-Vehicles in Europe.” *European Transport Research Review* 7 (3). Springer: 1–14.

Figenbaum, Erik, and Marika Kolbenstvedt. 2015. “Pathways to Electromobility-Perspectives Based on Norwegian Experiences.” *TØI, Report* 1420: 2015.

———. 2016. “Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle Users.” 1492/2016. Norwegian Center for Transport Research. https://www.toi.no/getfile.php?mmfileid=43161.

Fischer, Carolyn, Winston Harrington, and Ian W. H. Parry. 2007. “Should Automobile Fuel Economy Standards Be Tightened?” *Energy Journal* 28 (4): 1–29.

Fleming, Charles. 2015. “Fuel Cell Cars and Filling Stations Are Slow to Arrive.” *Los Angeles Times*, November 21. http://www.latimes.com/business/autos/la-fi-hy-fuel-cell-20151121-story.html.

Ford Truck Enthusiasts. 2014. “Ford F250 Gas vs Diesel - Ford-Trucks.” http://www.ford-trucks.com/how-tos/a/ford-f250-gas-vs-diesel-361891.

Frades, Matt, Nick Nigro, and Sandy Fazeli. 2015. “Development of Alternative Fuel Vehicle Market Needs a Multi-Pronged, Multi-Partner Approach.” *State & Local Energy Report*. http://stateenergyreport.com/2015/02/12/alternate-fuel/.

Friedman, Nicole. 2016. “Drivers, Don’t Buy Fancy Gasoline.” *WSJ*. wsj.com. September 20. http://blogs.wsj.com/moneybeat/2016/09/20/drivers-dont-buy-fancy-gasoline/.

Frisch, M., L. Solitare, M. Greenberg, and K. Lowrie. 1998. “Regional Economic Benefits of Environmental Management at the US Department of Energy’s Major Nuclear Weapons Sites.” *Journal of Environmental Management* 54 (1). Elsevier: 23–37.

Gallagher, Kelly Sims, and Erich Muehlegger. 2011. “Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology.” *Journal of Environmental Economics and Management* 61 (1): 1–15.

Gardner, Greg. 2016. “GM Launches Shared-Ride Service Called Maven.” *USA Today*, January 21. http://www.usatoday.com/story/money/cars/2016/01/21/gm-launches-shared-ride-service-called-maven/79103036/.

Gass, V., J. Schmidt, and E. Schmid. 2014. “Analysis of Alternative Policy Instruments to Promote Electric Vehicles in Austria.” *Renewable Energy* 61: 96–101.

Gayer, Ted, and Emily Parker. 2013. “Cash for Clunkers: An Evaluation of the Car Allowance Rebate System.” Brookings Institution. https://www.brookings.edu/wp-content/uploads/2016/06/cash_for_clunkers_evaluation_paper_gayer.pdf.

Gayer, Ted, and W. Kip Viscusi. 2013. “Overriding Consumer Preferences with Energy Regulations.” *Journal of Regulatory Economics* 43 (3). Springer US: 248–64.

Gelman, Michael, Yuriy Gorodnichenko, Shachar Kariv, Dmitri Koustas, Matthew D. Shapiro, Dan Silverman, and Steven Tadelis. 2016. “The Response of Consumer Spending to Changes in Gasoline Prices.” w22969. National Bureau of Economic Research. http://www.nber.org/papers/w22969.pdf.

Gerard, David, and Lester Lave. 2003. “The Economics of CAFE Reconsidered: A Response to CAFE Critics and a Case for Fuel Economy Standards.” *AEI-Brookings Joint Center for Regulatory Studies, Regulatory Analysis*, 03–01.

German, John. 2015. “Hybrid Vehicles - Technology Development and Cost Reduction.” Technical Brief 1. The International Council on Clean Transportation (ICCT). http://www.theicct.org/sites/default/files/publications/ICCT_TechBriefNo1_Hybrids_July2015.pdf.

———. Letter to John D. Graham. 2016a.

———. Letter to John D. Graham. 2016b, June 8.

German, John, and Nic Lutsey. 2010. “Size or Mass? The Technical Rationale for Selecting Size as an Attribute for Vehicle Efficiency Standards.” 9. International Council on Clean Transportation. http://www.theicct.org/sites/default/files/publications/ICCTpaper_sizewt_final.pdf.

Gibbs, Samuel. 2014. “Battle for the Car: Will Google, Apple or Microsoft Dominate?” *The Guardian*, March 6. http://www.theguardian.com/technology/2014/mar/06/battle-for-car-will-google-apple-microsoft-dominate.

Gillingham, Kenneth, Alan Jenn, and Inês L. Azevedo. 2015. “Heterogeneity in the Response to Gasoline Prices: Evidence from Pennsylvania and Implications for the Rebound Effect.” *Energy Economics* 52, Supplement 1 (December): S41–52.

Gilmore, Elisabeth A., and Lester B. Lave. 2013. “Comparing Resale Prices and Total Cost of Ownership for Gasoline, Hybrid and Diesel Passenger Cars and Trucks.” *Transport Policy* 27 (May): 200–208.

Glassman, James K. 2016. “Attention, Candidates: China Is Trying to Foil Aluminum.” *RealClear Politics*. June 17. http://www.realclearpolitics.com/articles/2016/06/17/attention_candidates_china_is_trying_to_foil_aluminum_130904.html.

Gold, Russell. 2015. “No End in Sight for Oil Glut.” *WSJ Online Article*, August 21. http://www.wsj.com/articles/no-end-in-sight-for-oil-glut-1440113703.

Goolsbee, Austan D., and Alan B. Krueger. 2015. “A Retrospective Look at Rescuing and Restructuring General Motors and Chrysler.” *The Journal of Economic Perspectives: A Journal of the American Economic Association* 29 (2): 3–23.

Goulder, Lawrence H., Mark R. Jacobsen, and Arthur A. van Benthem. 2012. “Unintended Consequences from Nested State and Federal Regulations: The Case of the Pavley Greenhouse-Gas-per-Mile Limits.” *Journal of Environmental Economics and Management* 63 (2). Elsevier: 187–207.

Goulder, Lawrence H., and Robert N. Stavins. 2012. “Interactions between State and Federal Climate Change Policies.” *The Design and Implementation of US Climate Policy*. University of Chicago Press, 109.

Graham, John D. 2010. *Bush on the Home Front: Domestic Policy Triumphs and Setbacks*. Indiana University Press.

———. 2016. *Obama on the Home Front: Domestic Policy Triumphs and Setbacks*. Indiana University Press.

Graham, John D., Joshua Cisney, Sanya Carley, and John Rupp. 2014. “No Time for Pessimism about Electric Cars.” *Issues in Science and Technology* 31 (1). Issues in Science and Technology: 33.

Graham-Rowe, Ella, Benjamin Gardner, Charles Abraham, Stephen Skippon, Helga Dittmar, Rebecca Hutchins, and Jenny Stannard. 2012. “Mainstream Consumers Driving Plug-in Battery-Electric and Plug-in Hybrid Electric Cars: A Qualitative Analysis of Responses and Evaluations.” *Transportation Research Part A: Policy and Practice* 46 (1): 140–53.

Granade, Hannah Choi, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, and Ken Ostrowski. 2009. “Unlocking Energy Efficiency in the U.S. Economy.” McKinsey & Company.

Greene, David L. 2010. “Why the Market for New Passenger Cars Generally Undervalues Fuel Economy.” OECD/ITF Joint Transport Research Centre Discussion Papers. doi:10.1787/5kmjp68qtm6f-en.

———. 1990. “CAFE OR PRICE?: An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89.” *Energy Journal* 11 (3). International Association for Energy Economics: 37–58.

———. 1998. “Why CAFE Worked.” *Energy Policy* 26 (8): 595–613.

———. 2011. “Uncertainty, Loss Aversion, and Markets for Energy Efficiency.” *Energy Economics* 33 (4): 608–16.

Greene, David L., David H. Evans, and John Hiestand. 2013. “Survey Evidence on the Willingness of U.S. Consumers to Pay for Automotive Fuel Economy.” *Energy Policy* 61 (October): 1539–50.

Greene, David L., John German, and Mark A. Delucchi. 2008. “Fuel Economy: The Case for Market Failure.” In *Reducing Climate Impacts in the Transportation Sector*, edited by James S. Cannon and Daniel Sperling, 181–205. Springer Netherlands.

Greene, David L., and Jilleah G. Welch. 2016. “The Impact of Increased Fuel Economy for Light-Duty Vehicles on the Distribution of Income in the United States.” Baker Reports 5:16. The Howard H. Baker Jr. Center for Public Policy.

Greimel, Hans. 2015. “Japan Brands’ Impact on U.S. Economy Expands, Study Says.” *Automotive News*. http://www.autonews.com/article/20151024/RETAIL01/310269988/japan-brands-impact-on-u.s.-economy-expands-study-says.

———. 2016. “IHS: China, Emerging Markets Will Power Surge in Global Sales.” *Automotive News*. March 7. http://www.autonews.com/article/20160307/GLOBAL/303079983/ihs%3A-china-emerging-markets--will-power-surge-in-global-sales.

Grossman, Andrew. 2009. “Foreign Rivals to Top Big Three in Key Metric.” *WSJ*. wsj.com. June 23. http://www.wsj.com/articles/SB124571198699038887.

Gruenspecht, Howard. 2001,. “Zero-Emission Vehicles: A Dirty Little Secret.” 142. Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Resources-142-zeroemmis.pdf.

Hagerty, James R., and Jeff Bennett. 2015. “U.S. Car-Making Boom? Not for Auto-Industry Workers.” *Wall Street Journal*, March 23. http://www.wsj.com/articles/u-s-car-making-boom-not-for-workers-1427154627.

Hamilton, James D. 2011. “Nonlinearities and the Macroeconomic Effects of Oil Prices.” *Macroeconomic Dynamics* 15 (S3). Cambridge University Press: 364–78.

Harder, Amy. 2016. “EPA Proposes Requiring 700 Million Gallons More of Ethanol in Gasoline in 2017.” *WSJ Online Article*, May 19. http://www.wsj.com/articles/epa-proposes-requiring-700-million-gallons-more-of-ethanol-in-gasoline-in-2017-1463597661.

Hastings, Justine S., and Jesse M. Shapiro. 2013. “Fungibility and Consumer Choice: Evidence from Commodity Price Shocks.” *The Quarterly Journal of Economics*, October. doi:10.1093/qje/qjt018.

Hayes, Dermot, Bruce Babcock, Jacinto Fabiosa, Simla Tokgoz, Amani Elobeid, Tun-Hsiang Yu, Fengxia Dong, et al. 2009. “Biofuels: Potential Production Capacity, Effects on Grain and Livestock Sectors, and Implications for Food Prices and Consumers.” *Journal of Applied Agricultural Economics* 41 (02). Cambridge Univ Press: 465–91.

Healey, James R. 2011. "Prius, Other Hybrids Lose Calif. Carpool Lane Access Today." *USA Today*, July 1. http://content.usatoday.com/communities/driveon/post/2011/06/prius-insight-worthless-hov-sticker-california-clean-air-carpool-lanes-volt-leaf-transit-connect-electric--/1.

Healey, Tim. 2016. "Cheap Gas Is Hurting Electrified Vehicle Residual Values." *HybridCars.com*. February 19. http://www.hybridcars.com/cheap-gas-hurts-ev-residual-values/.

Helfand, Gloria, and Reid Dorsey-Palmateer. 2015. "The Energy Efficiency Gap in EPA's Benefit-Cost Analysis of Vehicle Greenhouse Gas Regulations: A Case Study." *Journal of Benefit-Cost Analysis* 6 (2). Cambridge University Press: 432–54.

Helfand, Gloria, Michael McWilliams, Kevin Bolon, Lawrence Reichle, Mandy Sha, Amanda Smith, and Robert Beach. 2016. "Searching for Hidden Costs: A Technology-Based Approach to the Energy Efficiency Gap in Light-Duty Vehicles." *Energy Policy* 98 (November): 590–606.

Helveston, John Paul, Yimin Liu, Elea Mcdonnell Feit, Erica Fuchs, Erica Klampfl, and Jeremy J. Michalek. 2015. "Will Subsidies Drive Electric Vehicle Adoption? Measuring Consumer Preferences in the U.S. and China." *Transportation Research Part A: Policy and Practice* 73: 96–112.

Henry, Jim. 2016. "Mercedes Finds a Better Way around the 'Chicken Tax.'" *Automotive News*. http://www.autonews.com/article/20161203/OEM/312059954/mercedes-finds-a-better-way-around-the-chicken-tax.

Hetzner, Christiaan. 2016. "VW Goal: 1 Million Electrified Vehicles by 2025." *Automotive News*. May 29. http://www.autonews.com/article/20160529/OEM05/305309985/vw-goal%3A-1-million-electrified-vehicles-by-2025.

Higgins, Matthew, Thomas Klitgaard, and Robert Lerman. 2006. "Recycling Petrodollars." *Current Issues in Economics and Finance* 12 (9).

Higgins, Tim. 2016. "Tesla Posts Second Profitable Quarter Ever." *WSJ Online Article*, October 27. http://www.wsj.com/articles/tesla-posts-second-profitable-quarter-ever-1477513454.

———. 2017. "Tesla Misses Its 2016 Sales Goal, Despite 27% Fourth-Quarter Rise." *WSJ Online Article*, January 3. http://www.wsj.com/articles/tesla-misses-its-2016-sales-goal-despite-27-fourth-quarter-rise-1483479562.

Hill, Kim, Debra Maranger Menk, Joshua Cregger, and Michael Schultz. 2015. "Contribution of the Automotive Industry to the Economies of All Fifty States and the United States." Center for Automotive Research (CAR).

Hilsenrath, Jon, and Mike Spector. 2015. "Auto Market Reflects Fed's Dilemma." *Wall Street Journal*, September 15. http://www.wsj.com/articles/after-speedy-recovery-will-fed-tap-the-brakes-on-u-s-auto-sales-1442314801.

Hirsch, Jerry. 2011. "Electric Car Prices: Electric Cars about to Cost More in California." *Latimes*. July 11. http://articles.latimes.com/2011/jul/21/business/la-fi-autos-electric-prices-20110721.

———. 2015a. "Honda Accord Beats Toyota Prius as Top Seller in California." *Los Angeles Times*, February 13. http://www.latimes.com/business/autos/la-fi-hy-accord-prius-20150214-story.html.

———. 2015b. "Ford's Aluminum F-150 to Cost More for Repairs, Insurer Group Says." *Los Angeles Times*, July 30. http://www.latimes.com/business/autos/la-fi-hy-ford-f150-repair-cost-20150729-story.html.

Hoekstra, Mark, Steven L. Puller, and Jeremy West. 2014. "Cash for Corollas: When Stimulus Reduces Spending." Working Paper Series. National Bureau of Economic Research. doi:10.3386/w20349.

Holland, Stephen P., Erin T. Mansur, Nicholas Z. Muller, and Andrew J. Yates. 2016. "Are There Environmental Benefits from Driving Electric Vehicles? The Importance of Local Factors." *The American Economic Review* 106 (12): 3700–3729.

Holtsmark, Bjart, and Anders Skonhoft. 2014. "The Norwegian Support and Subsidy Policy of Electric Cars. Should It Be Adopted by Other Countries?" *Environmental Science & Policy* 42 (October): 160–68.

Honda. 2017. "Home | Honda In America." *Honda In America*. https://hondainamerica.com/.

Hovland, Kjetil Malkenes. 2015. "Electric-Car Perks Put Norway in a Pinch." *Wall Street Journal*, September 18. http://www.wsj.com/articles/electric-car-perks-put-norway-in-a-pinch-1442601936.

Hymel, Kent M., and Kenneth A. Small. 2015. “The Rebound Effect for Automobile Travel: Asymmetric Response to Price Changes and Novel Features of the 2000s.” *Energy Economics* 49 (C): 93–103.

ICF. 2015. “Economic Analysis of US Decarbonization Pathways.” ICF, International.

IFC International. 2015. “California Transportation Electrification Assessment: Phase 3 Final Report.” http://www.caletc.com/wp-content/uploads/2016/08/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf.

Iliff, Laurence. 2016. “Mexico Prepares Its Defense of NAFTA.” *Automotive News*. http://www.autonews.com/article/20161204/GLOBAL/312059963/mexico-prepares-its-defense-of-nafta.

Institutional Investors Group on Climate Change. 2016. “Investor Expectations of Automotive Companies: Shifting Gears to Accelerate the Transition to Low Carbon Vehicles.” *Ceres*. https://www.ceres.org/resources/reports/investor-expectations-of-automotive-companies-shifting-gears-to-accelerate-the-transition-to-low-carbon-vehicles/view.

Insurance Institute for Highway Safety [IIHS]. 2015a. “Improved Vehicle Designs Bring down Death Rates.” *Status Report*, January 29. http://www.iihs.org/iihs/sr/statusreport/article/50/1/1.

———. 2015b. “Pricier Repairs for Aluminum F-150 than Steel Model in Fender-Benders.” *Insurance Institute for Highway Safety*. July 30. http://www.iihs.org/iihs/sr/statusreport/article/50/6/2.

Intergovernmental Panel for Climate Change [IPCC]. 2014. “Climate Change 2014 Synthesis Report.” https://www.ipcc.ch/report/ar5/syr/.

Internal Revenue Service [IRS]. 2006. “Some Ford and Mercury Vehicles Certified for the New Energy Tax Credit.” *Internal Revenue Service*. April 7. https://www.irs.gov/uac/some-ford-and-mercury-vehicles-certified-for-the-new-energy-tax-credit.

———. 2009. “Tax Credit for Ford Hybrids Begins Phase-Out.” *Internal Revenue Service*. April 16. https://www.irs.gov/uac/tax-credit-for-ford-hybrids-begins-phase-out.

International Council on Clean Transportation [ICCT]. 2012. “ICCT Comments in Response to the Proposed Rulemaking Issued by the National Highway Traffic Safety Administration and the Environmental Protection Agency on 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards.” NHTSA-2010-0131. International Council on Clean Transportation. http://www.theicct.org/sites/default/files/ICCT%20comments%20on%202017-25%20GHG%20NPRM_FINAL.pdf.

International Energy Agency [IEA]. 2015. “World Energy Outlook 2015.” http://www.worldenergyoutlook.org/weo2015/.

———. 2016. “Global EV Outlook 2016: Beyond One Million Electric Cars.” International Energy Agency. https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf.

Irwin, John. 2016a. “Wage Discontent Simmers at Suppliers.” *Automotive News*. July 17. http://www.autonews.com/article/20160717/OEM10/307189970/wage-discontent-simmers-at-suppliers.

———. 2016b. “Lighweighting Prompts Heavy Investment in Aluminum.” *Automotive News*. September 19. http://www.autonews.com/article/20160919/OEM10/309199997/lighweighting-prompts-heavy-investment-in-aluminum.

Jacobsen, Mark R. 2013. “Evaluating US Fuel Economy Standards in a Model with Producer and Household Heterogeneity.” *American Economic Journal: Economic Policy* 5 (2): 148–87.

Jacobsen, Mark R., and Arthur A. van Benthem. 2015. “Vehicle Scrappage and Gasoline Policy.” *The American Economic Review* 105 (3): 1312–38.

Jenkins, Jesse D., and Valerie J. Karplus. 2016. “Carbon Pricing under Binding Political Constraints 1 and.” 2016/44. World Institute for Development Economic Research (UNU-WIDER). https://www.wider.unu.edu/sites/default/files/wp2016-44.pdf.

Jenn, Alan, Inês M. L. Azevedo, and Jeremy J. Michalek. 2016. “Alternative Fuel Vehicle Adoption Increases Fleet Gasoline Consumption and Greenhouse Gas Emissions under United States Corporate Average Fuel Economy Policy and Greenhouse Gas Emissions Standards.” *Environmental Science & Technology* 50 (5): 2165–74.

Johnson, Scott Lee, and David M. Pekelney. 1996. “Economic Assessment of the Regional Clean Air Incentives Market: A New Emissions Trading Program for Los Angeles.” *Land Economics* 72 (3). [Board of Regents of the University of Wisconsin System, University of Wisconsin Press]: 277–97.

Jolly, David. 2015. “Norway Is a Model for Encouraging Electric Car Sales.” *The New York Times*, October 16. http://www.nytimes.com/2015/10/17/business/international/norway-is-global-model-for-encouraging-sales-of-electric-cars.html.

Jones, Clarissa. 2017. “Gas Prices: It’ll Cost $52B More for Us to Fill ‘Er up.” *WMAZ*. January 3. http://www.13wmaz.com/money/gas-prices-itll-cost-52b-more-for-us-to-fill-er-up/381837232.

Jones, Courtney. 2016. “2017 Toyota RAV4 Hybrid | U.S. News & World Report.” http://usnews.rankingsandreviews.com/cars-trucks/Toyota_RAV4-Hybrid/.

Kaenel, Camille von. 2016a. “Electric Car Sales Up Despite Low Gasoline Prices.” *E&E News*, July 14. https://www.scientificamerican.com/article/electric-car-sales-up-despite-low-gasoline-prices/.

———. 2016b. “House Republicans’ ZEV Fund in Settlement a ‘Curious Outcome.’” *E&E News*. November 1.

Kahn, Debra. 2016. “Pressure Builds on California to Adjust EV Incentives.” *E&E News*, July 26.

Kahneman, Daniel, Paul Slovic, and Amos Tversky. 1982. *Judgment Under Uncertainty: Heuristics and Biases*. Cambridge University Press.

Kammen, Daniel M., Samuel M. Arons, Derek Lemoine, and Holmes Hummel. 2008. “Cost-Effectiveness of Greenhouse Gas Emission Reductions from Plug-in Hybrid Electric Vehicles,” November. doi:10.2139/ssrn.1307101.

Kane, Mark. 2015. “Norway To Cut Some Electric Car Incentives.” *Inside EVs*. http://insideevs.com/norway-cut-electric-car-incentives/.

———. 2016. “California Removes Limit On Green HOV Stickers For PHEVs.” *Inside EVs*. http://insideevs.com/california-removes-limit-on-green-hov-stickers-for-phevs/.

Kantchev, Georgi, and Summer Said. 2015. “Russian Oil Output Rises to Post-Soviet High in September.” *WSJ Online Article*, October 3. http://www.wsj.com/articles/russian-oil-output-rises-to-post-soviet-high-in-september-1443777432.

Karplus, Valerie J., Sergey Paltsev, Mustafa Babiker, and John M. Reilly. 2013. “Should a Vehicle Fuel Economy Standard Be Combined with an Economy-Wide Greenhouse Gas Emissions Constraint? Implications for Energy and Climate Policy in the United States.” *Energy Economics* 36: 322–33.

Kellogg, Alex, and Josh Mitchell. 2009. “Lean Inventories Imperil Car Sales.” *Wall Street Journal*. wsj.com. August 6. http://www.wsj.com/articles/SB124943011168206233.

Khanna, Shefali, and Joshua Linn. 2013. “Do Market Shares or Technology Explain Rising New Vehicle Fuel Economy?” *Resources for the Future Discussion Paper*, September. papers.ssrn.com. doi:10.2139/ssrn.2328314.

Kim. 2010. “Toyota Pushes Back U.S. Prius Production by Years.” *Reuters*. July 27. http://www.reuters.com/article/us-toyota-idUSTRE66O07V20100727.

Klein, Jonathan. 2007. “Why People Really Buy Hybrids.” The Topline Strategy Group. http://www.cleanenergycouncil.org/files/Topline_Strategy_Report_Why_People_Really_Buy_Hybrids.pdf.

Kleit, Andrew N. 2004. “Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard.” *Economic Inquiry* 42 (2). Blackwell Publishing Ltd: 279–94.

Klier, Thomas, and Joshua Linn. 2010. “The Price of Gasoline and New Vehicle Fuel Economy: Evidence from Monthly Sales Data.” *American Economic Journal: Economic Policy* 2 (3): 134–53.

———. 2012. “New-Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard.” *RAND Journal of Economics* 43 (1): 186–213.

Kloßner, Stefan, and Gregor Pfeifer. 2015. “Synthesizing Cash for Clunkers: Stabilizing the Car Market, Hurting the Environment.” https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=RESConf2016&paper_id=504.

Knittel, Christopher R. 2009. “The Implied Cost of Carbon Dioxide under the Cash for Clunkers.” *SSRN Electronic Journal*, no. 1334747 (January). doi:10.2139/ssrn.1630647.

———. 2011. “Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector.” *The American Economic Review* 101 (7): 3368–99.

———. 2012. “Reducing Petroleum Consumption from Transportation.” *The Journal of Economic Perspectives: A Journal of the American Economic Association* 26 (1): 93–118.

———. 2014. “California’s Auto-Emissions Policy Hits a Tesla Pothole.” *WSJ Online Article*, February 14. http://www.wsj.com/articles/SB10001424052702303650204579376801103200852.

Krause, Rachel M., Sanya R. Carley, Bradley W. Lane, and John D. Graham. 2013. “Perception and Reality: Public Knowledge of Plug-in Electric Vehicles in 21 U.S. Cities.” *Energy Policy* 63: 433–40.

Krebs, Michelle. 2012. “Will Higher Gas Prices Boost Hybrid, EV Sales?” *Edmunds*. February 28. https://www.edmunds.com/industry-center/analysis/will-higher-gas-prices-boost-hybrid-ev-sales.html.

Kromer, Matthew A., and John B. Heywood. 2008. “A Comparative Assessment of Electric Propulsion Systems in the 2030 US Light-Duty Vehicle Fleet.” *SAE International Journal of Engines* 1 (2008-01-0459). papers.sae.org: 372–91.

KRT. 2005. “Tax Credit Adds Incentive to Buy Hybrid Vehicles.” *Chicago Tribune*. August 24. http://articles.chicagotribune.com/2005-08-24/news/0508240393_1_hybrid-vehicles-toyota-prius-tax-credit.

Krupnick, Alan, Joshua Linn, Virginia McConnel, and James Taylor. 2014. “Preparing for the Midterm Review of the Fuel Economy and Greenhouse Gas Emissions Rate Standards for Light-Duty Vehicles.” 14-04. Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-IB-14-04.pdf.

Kubota, Yoko. 2016. “Honda CEO Shifts Focus to Electric Vehicles.” *WSJ Online Article*, February 25. http://www.wsj.com/articles/honda-ceo-shifts-focus-to-electric-vehicles-1456307220.

Kühlwein, Jörg, John German, and A. Bandivadekar. 2014. “Development of Test Cycle Conversion Factors among Worldwide Light-Duty Vehicle CO2 Emission Standards.” 1225 I Street NW Suite 900 Washington DC 20005: International Council for Clean Transportation. http://www.theicct.org/sites/default/files/publications/ICCT_LDV-test-cycle-conversion-factors_sept2014.pdf.

Kurani, Kenneth S., Nicolette Caperello, and Jennifer TyreeHageman. 2016. “New Car Buyers’ Valuation of Zero-Emission Vehicles: California.” UCD-ITS-RR-16-05. University of California. https://www.arb.ca.gov/research/apr/past/12-332.pdf.

Kurylko, Diana T. 2013. “Transplants Keep Rolling in N. America.” *Automotive News*. April 22. http://www.autonews.com/article/20130422/OEM01/304229996/transplants-keep-rolling-in-n.-america.

Laing, Keith. 2017. “International Regulations May Offset U.S. Mpg Rollback.” *Detroit News*. January 17. http://www.detroitnews.com/story/business/autos/2017/01/16/international-regulations-may-offset-us-mpg-rollback/96652444/.

Lane, Bradley W., Natalie Messer-Betts, Devin Hartmann, and Sanya Carley. 2013. “Government Promotion of the Electric Car: Risk Management or Industrial Policy.” *Eur. J. Risk Reg*. HeinOnline, 227.

LaReau, Jamie. 2015. “Connecticut Offers EV Rebates to Jolt Sales.” *Automotive News*. August 23. http://www.autonews.com/article/20150823/RETAIL/308249987/connecticut-offers-ev-rebates-to-jolt-sales.

Larrick, Richard P., and Jack B. Soll. 2008. “The MPG Illusion.” *Science* 320 (June): 1593–94.

Leard, Benjamin, and Virginia McConnell. 2015. “New Markets for Pollution and Energy Efficiency: Credit Trading Under Automobile Greenhouse Gas and Fuel Economy Standards.” RFF DP 15-16. Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-15-16.pdf.

Leistikow, Dan. 2013. “The eGallon: How Much Cheaper Is It to Drive on Electricity?” *Energy.gov*. June 10. https://energy.gov/articles/egallon-how-much-cheaper-it-drive-electricity.

Leontief, Wassily. 1986. *Input-Output Economics*. 2nd ed. New York: Oxford University Press.

LeSage, Jon. 2016. “Surveys Show Challenges OEMs Face Selling Electric and Self-Driving Cars - HybridCars.com.” *HybridCars.com*. May 27. http://www.hybridcars.com/surveys-show-challenges-oems-face-selling-electric-and-self-driving-cars/.

Leung, L. R., and L. W. Vail. 2016. “Potential Impacts of Accelerated Climate Change - Annual Report of Work for NRC.” NRC-HQ-60-14-D-0025. National Research Council. https://www.nrc.gov/docs/ML1620/ML16208A282.pdf.

Levi, Michael. 2015. "Why the Oil Price Drop Matters." *World Economic Forum*. March 2. https://www.weforum.org/agenda/2015/03/why-the-oil-price-drop-matters/.

Libby, Tom. 2014. "Automotive Hybrid Model Counts Continue to Rise, but Sales Don't Keep Pace | IHS Blogs." May 30. http://blog.ihs.com/automotive-hybrid-model-counts-continue-to-rise2c-but-sales-done28099t-keep-pace.

Linn, Joshua, and Virginia McConnell. 2013. "How Electric Cars Can Increase Greenhouse Gas Emissions." Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Resources-184_Feature-LinnMcConnell.pdf.

Lippert, John. 2015. "California Has a Plan to End the Auto Industry as We Know It." *Bloomberg*. August 3. https://www.bloomberg.com/news/articles/2015-08-03/california-regulator-mary-nichols-may-transform-the-auto-industry.

Li, Shanjun, Joshua Linn, and Elisheba Spiller. 2013. "Evaluating 'Cash-for-Clunkers': Program Effects on Auto Sales and the Environment." *Journal of Environmental Economics and Management* 65 (2). Elsevier: 175–93.

Litman, Todd. 2016. "The Future Isn't What It Used To Be - Changing Trends And Their Implications For Transport Planning." Victoria Transport Policy Institute. http://www.vtpi.org/future.pdf.

Lo, Chris. 2015. "The False Monopoly: China and the Rare Earths Trade." *Mining Technology*. August 20. http://www.mining-technology.com/features/featurethe-false-monopoly-china-and-the-rare-earths-trade-4646712/.

Luger, S. 2005. *Corporate Power, American Democracy, and the Automobile Industry*. Cambridge University Press.

Luskin Donald L And. 2015. "The Shale Boom Shifts Into Higher Gear." *WSJ Online Article*, May 31. http://www.wsj.com/articles/the-shale-boom-shifts-into-higher-gear-1433104129.

Lutsey, Nic, Stephanie Searle, Sarah Chambliss, and Anup Bandivadekar. 2015. "Assessment of Leading Electric Vehicle Promotion Activities in United States Cities." The International Council on Clean Transportation. http://www.theicct.org/sites/default/files/publications/ICCT_EV-promotion-US-cities_20150729.pdf.

Mannix, Brian F. 2014. "10. Employment and Human Welfare: Why Does Benefit– Cost Analysis Seem Blind to Job Impacts?" In *Does Regulation Kill Jobs?*, edited by Cary Coglianese, Adam M. Finkel, and Christopher Carrigan. Philadelphia: University of Pennsylvania Press.

Martinez, Michael. 2017. "Ford F-150 to Gain a Diesel Option." *Automotive News*. January 9. http://www.autonews.com/article/20170109/OEM03/301099982/ford-f-150-to-gain-a-diesel-option.

McConnell, Virginia. 2013. "The New CAFE Standards: Are They Enough on Their Own?" Discussion Paper 13-14. doi:10.2139/ssrn.2291995.

McConnell, Virginia, and Tom Turrentine. 2010. "Should Hybrid Vehicles Be Subsidized?" Backgrounder. Resources for the Future. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-BCK-McConnellTurrentine-Hybrids.pdf.

McCormick, John. 2015. "Car Culture: King of Hybrids Prius Gets Royal Makeover." *Detroit News*. November 19. http://www.detroitnews.com/story/business/columnists/john-mccormick/2015/11/18/mccormick-prius-makeover-hybrid-toyota/76028006/.

McLain, Sean. 2016a. "Toyota's Prius Pays Price for Cheap Gasoline." *Wall Street Journal*, September 6. http://www.wsj.com/articles/toyotas-prius-pays-price-for-cheap-gasoline-1473149470.

———. 2016b. "Toyota Profit Falls on Strong Yen, Weak U.S. Sales." *Wall Street Journal*, November 9. http://www.wsj.com/articles/toyota-profit-falls-on-strong-yen-weak-u-s-sales-1478586115.

———. 2016c. "Toyota Sees the Battery-Power Light." *WSJ Online Article*, November 17. http://www.wsj.com/articles/toyota-sees-the-battery-power-light-1479370083.

Melaina, Marc, and Michael S. Helwig. 2014. "California Statewide Plug-In Electric Vehicle Infrastructure Assessment." S-2015. National Renewable Energy Laboratory. https://works.bepress.com/michael_helwig/2/.

Mello, Tara Baukus. 2016. "Delinquencies Rise with Longer Car-Loan Terms." *Bankrate.com*. July 17. http://www.bankrate.com/financing/cars/long-car-loan-some-consumers-get-out-others-get-late/.

Menzie, W. D., J. J. Barry, D. I. Bleiwas, E. L. Bray, T. G. Goonan, and Grecia Matos. 2010. "The Global Flow of Aluminum from 2006 through 2025." Open-File Report 2010-1256. US Geological Survey. https://pubs.usgs.gov/of/2010/1256/pdf/ofr2010-1256..pdf.

Mertl, Steve. 2016. “Few See Depreciation as the Major Vehicle Cost, Survey Says.” *Automotive News*. July 15. http://canada.autonews.com/article/20160715/CANADA/160719948/few-see-depreciation-as-the-major-vehicle-cost-survey-says.

Mian, Atif, and Amir Sufi. 2012. “The Effects of Fiscal Stimulus: Evidence from the 2009 Cash for Clunkers Program.” *The Quarterly Journal of Economics* 127 (3). Oxford University Press: 1107–42.

Michalek, Jeremy J., Mikhail Chester, Paulina Jaramillo, Constantine Samaras, Ching-Shin Norman Shiau, and Lester B. Lave. 2011. “Valuation of Plug-in Vehicle Life-Cycle Air Emissions and Oil Displacement Benefits.” *Proceedings of the National Academy of Sciences of the United States of America* 108 (40): 16554–58.

Millward, Steven. 2015. “Chinese Startups May Jolt EV Sales.” *Los Angeles Times*. https://www.pressreader.com/usa/los-angeles-times/20151229/281938836886360.

Mims, Christopher. 2016. “Why Electric Cars Will Be Here Sooner Than You Think.” *WSJ Online Article*, August 28. http://www.wsj.com/articles/why-electric-cars-will-be-here-sooner-than-you-think-1472402674.

Mitchell, Russ. 2016. “Electric Cars Are Less than 1% of the Market. Yet Automakers Are Pushing Them Big Time. Why?” *Los Angeles Times*, November 14. http://www.latimes.com/business/autos/la-fi-hy-electric-car-future-auto-show-20161114-story.html.

Montoya, Ronald. 2014. “Why Hybrids and Diesels Don’t Always Save You Money.” *Edmunds*. https://www.edmunds.com/car-buying/why-hybrids-and-diesels-dont-always-save-you-money.html.

Morath, Eric. 2014. “Lower Gas Prices Like Huge Tax Cut for Middle Class.” *Wall Street Journal*. http://blogs.wsj.com/economics/2014/12/10/lower-gas-prices-like-huge-tax-cut-for-middle-class/.

Morrow, W. Ross, Kelly Sims Gallagher, Gustavo Collantes, and Henry Lee. 2010. “Analysis of Policies to Reduce Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector.” Belfer Center for Science and International Affairs.

Motor and Equipment Manufacturers Association [MEMA]. 2013. “Moving America Forward.” https://www.mema.org/sites/default/files/MEMA%20Industry%20Study%202013.pdf.

Mulkern, Anne C. 2016. “CALIFORNIA: $363M Cap-and-Trade Cash Goes to Clean Cars, Transit.” *E&E News*. October 24. http://www.eenews.net/climatewire/stories/1060044686/search?keyword=+%24363+Million+Cap-and-Trade+Goes+to+Clean+Cars.

Murphy, Anthony, Michael Plante, and Mine Yücel. 2015. “Plunging Oil Prices: A Boost for the U.S. Economy, a Jolt for Texas.” *Federal Reserve Bank of Dallas*. https://www.dallasfed.org/assets/documents/research/eclett/2015/el1503.pdf.

Murtha, Philly. 2015. “2015 Initial Quality Study: 10 Most Important Factors in Vehicle Purchase.” *J.D. Power Cars*. July 13. http://www.jdpower.com/cars/articles/jd-power-studies/2015-initial-quality-study-10-most-important-factors-vehicle-purchase.

National Automobile Dealers Association. 2015. “NADA Used Car Guide Perspective: Electric Vehicle Retention Report Card.” McLean, VA.

National Highway Cooperation Research Program. 2001. “Economic Implications of Congestion.” 463. NRC.

National Highway Traffic Safety Administration [NHTSA]. 2009. “Consumer Assistance to Recycle and Save Act of 2009.” In *Report to Congress*.

———. 2010. “Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks.”

———. 2012a. “Final Regulatory Impact Analysis - Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks.”

———. 2012b. “Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025.” DOT HS 811 666.

National Research Council [NRC]. 1996. *Shopping for Safety: Providing Consumer Automotive Safety Information*. Special Report. Washington, D.C.: Transportation Research Board, National Academies Press.

———. 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. Washington D.C.: National Academy Press.

———. 2010. *Alternative Transportation Technologies - Plug-in Hybrid Electric Vehicles*. Washington D.C.: The National Academies Press.

———. 2015a. *Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles*. Washington, D.C.: National Academies Press.

———. 2015b. *Overcoming Barriers to Deployment of Plug-in Electric Vehicles*. Washington, DC: The National Academies Press.

Naughton, Keith. 2016. "Ford Plans Long-Range Electric Car to Compete With Tesla, GM." *Bloomberg.com*. https://www.bloomberg.com/news/articles/2016-04-28/ford-plans-long-range-electric-car-to-compete-with-tesla-gm.

Needell, Zachary A., James McNerney, Michael T. Chang, and Jessika E. Trancik. 2016. "Potential for Widespread Electrification of Personal Vehicle Travel in the United States." *Nature Energy* 1 (August). Nature Publishing Group: 16112.

Nelson, Gabe. 2013a. "As Obama's CO2 Regulations Get Tough, Automakers -- Especially Japanese -- Have Already Earned a Big Cushion." *Automotive News*. http://www.autonews.com/article/20130408/OEM01/304089970/as-obamas-co2-regulations-get-tough-automakers----especially-japanese-.

———. 2013b. "Daimler Asks EPA to Let Tech Features Bolster Its Mileage Ratings." *Automotive News*. http://www.autonews.com/article/20131104/OEM06/311049962/daimler-asks-epa-to-let-tech-features-bolster-its-mileage-ratings.

———. 2015. "Calif. Considers a Plea for Plug-in Hybrids." *Automotive News*. http://www.autonews.com/article/20150328/OEM05/303309999/calif.-considers-a-plea-for-plug-in-hybrids.

Nicholson Jessica R, Noonan, Ryan. 2014. "What Is Made in America?" 04-14. US Department of Commerce. http://www.esa.doc.gov/sites/default/files/whatismadeinamerica_0.pdf.

Niedermeyer, Edward. 2016. "10 True Facts From Tesla's Model 3 CAEATFA Application." *DailyKanban*. October 4. http://dailykanban.com/2016/10/10-true-facts-teslas-model-3-caeatfa-application/.

Nivola, Pietro S., and Robert W. Crandall. 1995. *The Extra Mile: Rethinking Energy Policy for Automotive Transportation*. The Brookings Institution.

Novation Analytics, LLC. 2015. "Technology Effectiveness - Phase 1: Fleet-Level Assessment (version 1.1)." Alliance of Automobile Manufacturers, Association of Global Automakers.

Nykvist, Björn, and Måns Nilsson. 2015. "Rapidly Falling Costs of Battery Packs for Electric Vehicles." *Nature Climate Change* 5 (4). Nature Research: 329–32.

Office of the Federal Register. 2016. "Civil Penalties." A Rule by the National Highway Traffic Safety Administration. *NHTSA*. https://www.federalregister.gov/documents/2016/12/28/2016-31136/civil-penalties.

Oge, Margo T. 2015. "Why Auto-Emission Rules Are Good for the Economy." *CNBC*. CNBC. April 21. http://www.cnbc.com/2015/04/21/why-auto-emission-rules-are-good-for-the-economy-commentary.html.

Orcutt, Mike. 2015. "Inexpensive Electric Cars May Arrive Sooner Than You Think." *MIT Technology Review*, April 2. https://www.technologyreview.com/s/536336/inexpensive-electric-cars-may-arrive-sooner-than-you-think/.

Peterson, Scott B., and Jeremy J. Michalek. 2013. "Cost-Effectiveness of Plug-in Hybrid Electric Vehicle Battery Capacity and Charging Infrastructure Investment for Reducing US Gasoline Consumption." *Energy Policy* 52: 429–38.

Phadke, Himani, Andrew Collins, Henrik Cotran, Stephanie Glazer, Anton Gorodniuk, Jerome Lavigne-Delville, Nashat Moin, Arturo Rodriguez, Jean Rogers, and Gabriella Vozza. 2014. "Iron & Steel Producers." Sustainability Accounting Standards Board. http://www.sasb.org/wp-content/uploads/2014/06/NR0301_IronSteelProducers_2014_06_24_Industry_Brief.pdf.

Plug In America. 2016. "Evaluating Methods to Encourage Plug-In Electric Vehicle Adoption: A Review of Reports on PEV Incentive Effectiveness for California Utilities." Caltech. http://www.caletc.com/wp-content/uploads/2016/10/PIA-Incentive-Survey-Paper-CS5-final-cosmetic.pdf.

Polk, R. L. &. Co. 2002. "Valid Registration Types and Their Meaning."

———. 2016. "Vehicle Registration Data." Proprietary information.

Popiel, S. 2011. "From Nozzle to Plug: Achieving Zero Emissions." In *SAE 2011 Hybrid Vehicle Symposium. Anaheim, California*.

Pricewaterhouse Coopers LLP [PwC]. 2013. "Economic Impacts of the Oil and Natural Gas Industry on the US Economy in 2011." American Petroleum Institute. http://www.api.org/~/media/Files/Policy/Jobs/Economic_Impacts_ONG_2011.pdf.

Proctor, Bernadette D., Jessica L. Semega, and Melissa A. Kollar. 2016. "Income and Poverty in the United States: 2015." P60-256(RV). United States Census Bureau. http://www.uah.org/wp-content/uploads/2016/09/here.pdf.

Prusa, Thomas J. 2015. "The Contribution of the Japanese-Brand Automotive Industry to the United States Economy - 2014 Update." Japan Automobile Manufacturers Association. http://www.jama.org/wp-content/uploads/2015/10/Prusa-JAMA-Prusa-Study-2014_Final2.pdf.

Pugliaresi, Lucian, and Max Pyziur. 2016. "CAFE Program Midterm Evaluation Should Consider Oil-Market Changes." *Oil & Gas Journal*. April 4. http://www.ogj.com/articles/print/volume-114/issue-4/general-interest/cafe-program-midterm-evaluation-should-consider-oil-market-changes.html.

Ramsey, Mike. 2014. "Atlanta's Incentives Lift Electric Car Sales." *Wall Street Journal*, June 4. http://www.wsj.com/articles/why-electric-cars-click-for-atlanta-1401922534.

———. 2015. "Beijing Auto Group Opens Center in Silicon Valley." *WSJ Online Article*, September 10. http://www.wsj.com/articles/beijing-auto-group-opens-center-in-silicon-valley-1441904922.

———. 2016. "Startups Aim to Get a Piece of the Driverless Car." *WSJ Online Article*. http://www.wsj.com/articles/startups-aim-to-get-a-piece-of-the-driverless-car-1453690985.

Ransom, Kevin. 2008. "Reasons to Buy a Hybrid -- or Not - CNN.com." *CNN*. January 28. http://www.cnn.com/2008/LIVING/wayoflife/01/28/buy.hybrid/index.html?iref=nextin.

Rascoe, Ayesha, and Deepa Seetharaman. 2013. "U.S. Backs off Goal of One Million Electric Cars by 2015." *Reuters*. January 31. http://www.reuters.com/article/us-autos-greencars-chu-idUSBRE90U1B020130131.

Rechtin, Mark. 2012. "Reports of EV Death Premature." *Automotive News*. December 3. http://www.autonews.com/article/20121203/OEM03/312039963/reports-of-ev-death-premature.

Redfoot, Donald, Lynn Feinberg, and Ari Houser. 2013. "The Aging of the Baby Boom and the Growing Care Gap: A Look at Future Declines in the Availability of Family Caregivers." *Insight on the Issues* 85. http://www.giaging.org/documents/AARP_baby-boom-and-the-growing-care-gap-insight-AARP-ppi-ltc.pdf.

Reuters. 2016. "BMW Confirms Plans to Offer Electric X3 and Mini Models." *Fortune*. September 30. http://fortune.com/2016/09/30/bmw-electric-x3-mini/.

Rocco, Matthew. 2015. "Toyota-Mazda Alliance Reflects Swelling Auto Costs," May. Fox Business. http://www.foxbusiness.com/features/2015/05/13/toyota-mazda-alliance-reflects-swelling-auto-costs.html.

Rogers, Christina. 2014. "Sonic Automotive to Start Used-Car Dealership Chain." *Wall Street Journal*, August 18. http://www.wsj.com/articles/sonic-automotive-to-start-used-car-dealership-chain-1408335055.

Roland-Holst, David. 2011. "Driving California's Economy: How Fuel Economy and Emissions Standards Will Impact Economic Growth and Job Creation." https://trid.trb.org/view.aspx?id=1245415.

Roland, Neil. 2009. "Experts Urge New Technologies Be Stirred into CAFE Scores." *Automotive News*. http://www.autonews.com/article/20091116/OEM05/311169865/experts-urge-new-technologies-be-stirred-into-cafe-scores.

Roosen, Jorg, Wim Marneffe, and Lode Vereeck. 2015. "A Review of Comparative Vehicle Cost Analysis." *Transport Reviews* 35 (6): 720–48.

Rosenfeld, Arthur, Celina Atkinson, Jonathan Koomey, Alan Meier, Robert J. Mowris, and Lynn Price. 1993. "Conserved Energy Supply Curves for U.S. Buildings." *Contemporary Economic Policy* 11 (1): 45–68.

Roth, Kevin. 2014. "The Unintended Consequences of Uncoordinated Regulation: Evidence from the Transportation Sector." University of California-Irvine. https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=IAAE2014&paper_id=484.

Ryan, Nancy E., and Luke Lavin. 2015. "Engaging Utilities and Regulators on Transportation Electrification." Energy + Environmental Economics, Inc. http://www.sciencedirect.com/science/article/pii/S1040619015000755.

Sabatini, Jeff. 2016. "2016 Toyota RAV4 Hybrid AWD - Instrumented Test." June 1. http://www.caranddriver.com/reviews/2016-toyota-rav4-hybrid-awd-test-review.

Sallee, James M. 2010. "The Taxation of Fuel Economy. V Chapter 1 in Jeffrey Brown, Ed." *Tax Policy and the Economy* 25.

Sallee, James M., Sarah E. West, and Wei Fan. 2016. "Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations." *Journal of Public Economics* 135: 61–73.

Samaras, Constantine, and Kyle Meisterling. 2008. "Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy." *Environmental Science & Technology* 42 (9). ACS Publications: 3170–76.

Sandalow, David B. 2009. *Plug-In Electric Vehicles: What Role for Washington?* Brookings Institution Press.

Saulsbury, Bo, Janet L. Hopson, David L. Green, and Robert Gibson. 2015. "Status and Issues for Consumer Fuel Economy in the United States: Alternative Fuels and Advanced Vehicle Market Trends." DE-AC05-00OR22725. Oak Ridge National Laboratory. https://cleancities.energy.gov/files/u/news_events/document/document_url/91/2015_strategic_planning_fuel_economy.pdf.

Sawyers, Arlena. 2009, April 7. "Scrap Incentives Would Hurt Late-Model Prices, Economist Says." *Automotive News*. http://www.autonews.com/article/20090407/RETAIL04/304079928/scrap-incentives-would-hurt-late-model-prices-economist-says.

———. 2009. "'Cash for Guzzlers' Is Chaos for Used-Car Prices." *Automotive News*. http://www.autonews.com/article/20090525/RETAIL04/305259903/cash-for-guzzlers-is-chaos-for-used-car-prices.

———. 2015. "Lights out on EV Incentives in Some States." *Automotive News*. http://www.autonews.com/article/20150606/OEM05/306089954/lights-out-on-ev-incentives-in-some-states.

———. 2016. "Cheap Gas Hits Hybrid, EV Residuals." *Automotive News*. January 30. http://www.autonews.com/article/20160130/OEM05/302019987/cheap-gas-hits-hybrid-ev-residuals.

Schmitt, Bertel. 2016. "Thinner Air For Tesla With Toyota Apparently Set To Join Battery EV Fray." *Forbes*. November 7. http://www.forbes.com/sites/bertelschmitt/2016/11/07/thinner-air-for-tesla-as-toyota-joins-the-bev-fray-a-natural-consequence/.

Schoenfeld, Almut, and Marcus Walker. 2009. "Germany's 'Scrap' Bonus Fuels Car Sales." *Wall Street Journal*. wsj.com. February 28. http://www.wsj.com/articles/SB123578485862598527.

Schoettle, Brandon, and Michael Sivak. 2016. "Consumer Preferences for the Charging of Plug-In Electric Vehicles." SWT-2016-13. University of Michigan Sustainable Worldwide Transportation.

Schwer, R. Keith, and Mary Riddel. 2004. *The Potential Economic Impact of Constructing and Operating Solar Power Generation Facilities in Nevada*. National Renewable Energy Laboratory.

Sedgwick, David. 2014. "Supplier Sees a Path to 54.5 Mpg without EVs." *Automotive News*. January 20. http://www.autonews.com/article/20140120/OEM09/301209939/supplier-sees-a-path-to-54.5-mpg-without-evs.

———. 2016. "Johnson Controls Bets Big on Stop-Start Systems." *Automotive News*. July 4. http://www.autonews.com/article/20160704/OEM02/307049991/johnson-controls-bets-big-on-stop-start-systems.

Seefeldt, Kristin S., John David Graham, Gordon Abner, and Tavis Smiley. 2013. *America's Poor and the Great Recession*. Indiana University Press.

Sewell, Abby, Kate Mather, and Ari Bloomekatz. 2011. "Hybrids, Carpool Lanes: For Hybrid Drivers on California Freeways, It's Now the Past Lane." *Los Angeles Times*. http://articles.latimes.com/2011/jul/02/local/la-me-07-02-carpool-lanes-20110702.

Shah, Neil. 2013. "More Commuters Go It Alone." *The Wallstreet Journal*.

Shamit. 2008. “J.D. Power Sees Three-Fold Growth for Hybrids by 2015.” *HybridCars.com*. April 8. http://www.hybridcars.com/jd-power-forecasts-three-fold-growth-hybrids-and-diesels/.

Sharman, Andy. 2014. “Carmakers Are Looking out on a Road Littered with Hazards.” *Financial Times*. November 20. https://www.ft.com/content/b2761b7e-6439-11e4-bac8-00144feabdc0.

Sharma, R., C. Manzie, M. Bessede, M. J. Brear, and R. H. Crawford. 2012. “Conventional, Hybrid and Electric Vehicles for Australian Driving Conditions – Part 1: Technical and Financial Analysis.” *Transportation Research Part C: Emerging Technologies* 25 (December): 238–49.

Shelton, Sarah. 2015. “Automakers: Increase CARB Credit For Plug-In Hybrids.” *HybridCars.com*. March 30. http://www.hybridcars.com/automakers-increase-carb-credit-for-plug-ins/.

Shepardson, David. 2016. “U.S. May Not Hit One Million Electric Vehicles until 2020: Official.” *Reuters*. January 21. http://www.reuters.com/article/us-autos-electric-moniz-idUSKCN0UZ2MK.

Sheppard, David, and Anjli Raval. 2015. “Oil Price War Set to Open Iranian Front.” *DAWN.COM*. July 21. http://www.dawn.com/news/1195298.

Sherman, Hugh, and David S. Chappell. 1998. “Methodological Challenges in Evaluating Business Incubator Outcomes.” *Economic Development Quarterly* 11 (4). Sage Publications, Inc.: 313–21.

Shiau, Ching-Shin Norman, Jeremy J. Michalek, and Chris T. Hendrickson. 2009. “A Structural Analysis of Vehicle Design Responses to Corporate Average Fuel Economy Policy.” *Transportation Research Part A: Policy and Practice* 43 (9–10): 814–28.

Shulock, Chuck. 2016. “Manufacturer Sales Under the Zero Emission Vehicle Regulation: 2012 Expectations and Governors’ Commitments Versus Today’s Likely Outcomes.” Shulock Consulting. https://www.nrdc.org/sites/default/files/media-uploads/nrdc_commissioned_zev_report_july_2016_0.pdf.

Siddiki, Saba, Jerome Dumortier, Cali Curley, John D. Graham, Sanya Carley, and Rachel M. Krause. 2015a. “Exploring Drivers of Innovative Technology Adoption Intention: The Case of Plug-In Vehicles.” *The Review of Policy Research* 32 (6): 649–74.

Siders, David. 2015. “Jerry Brown Wants All New Cars in California Zero-Emission by 2050.” *Sacbee*. http://www.sacbee.com/news/politics-government/capitol-alert/article47817950.html.

Sierzchula, William, Sjoerd Bakker, Kees Maat, and Bert van Wee. 2014. “The Influence of Financial Incentives and Other Socio-Economic Factors on Electric Vehicle Adoption.” *Energy Policy* 68: 183–94.

Simmons, Richard A., Gregory M. Shaver, Wallace E. Tyner, and Suresh V. Garimella. 2015. “A Benefit-Cost Assessment of New Vehicle Technologies and Fuel Economy in the U.S. Market.” *Applied Energy* 157 (November): 940–52.

Simon, Herbert Alexander. 1976. *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization*. Free Press.

Sivak, Michael, and Brandon Schoettle. 2016a. “Recent Decreases in the Proportion of Persons With A Driver’s License Across All Age Groups.” UMTRI-2016-4. University of Michigan Transportation Institute. http://www.umich.edu/~umtriswt/PDF/UMTRI-2016-4.pdf.

———. 2016b. “Transportation Emissions in the Context of Emissions from Other July 201 Economic Sectors: 1990-2014.” SWT-2016-9. University of Michigan. http://www.umich.edu/~umtriswt/PDF/SWT-2016-9_Abstract_English.pdf.

———. 2017. “Vehicle Fuel Economy in the US Down Last Month.” University of Michigan.

Sivaram, Varun, and Michael A. Levi. 2015. “Automobile Fuel Economy Standards in a Lower-Oil-Price World.” Council on Foreign Relations.

Skowronski, Jeanine. 2015. “Survey: Americas Best Savers Are Not The Wealthy.” *Bankrate.com*. http://www.bankrate.com/finance/consumer-index/americas-best-savers-are-not-the-wealthy.aspx.

Small, Kenneth A. 2010. “Energy Policies for Automobile Transportation: A Comparison Using the National Energy Modeling System.” Resources for the Future. http://www.rff.org/files/sharepoint/Documents/Features/NEPI/RFF-BCK-Small-AutoPolicies.pdf.

Smith, Brett. 2016. “An Assessment of Powertrain Technology Costs Associated with Meeting CAFE and GHG Standards.” Center for Automotive Research.

Snyder, Jesse. 2016. “Fleet Does More Than Its Share for 2015 Sales.” *Automotive News*. January 18. https://www.autonews.com/article/20160118/RETAIL/301189979/fleet-does-more-than-its-share-for-15-sales.

Soper, Spencer, Bradley Olson, and Matthew Townsend. 2015. “How Americans Are Spending Their Windfall From Cheap Gas.” *Bloomberg*. https://www.bloomberg.com/news/articles/2015-02-02/how-we-re-spending-our-windfall-from-cheap-gas.

Sparshott, Jeffrey. 2015. “Study: Wealthy Claim Most Energy Credits.” *WSJ Online Article*, September 25. http://www.wsj.com/articles/study-wealthy-claim-most-energy-credits-1443150868.

Stepp, Erin. 2016. “U.S. Drivers Waste $2.1 Billion Annually on Premium Gasoline | AAA NewsRoom.” *AAA NewsRoom*. September 20. http://newsroom.aaa.com/2016/09/u-s-drivers-waste-2-1-billion-annually-premium-gasoline/.

Stevens, Benjamin H., George I. Treyz, David J. Ehrlich, and James R. Bower. 1983. “A New Technique for the Construction of Non-Survey Regional Input-Output Models.” *International Regional Science Review* 8 (3). Sage Publications Sage CA: Thousand Oaks, CA: 271–86.

Swiecki, Bernard, and Debra Menk. 2016. “CAR Research Publications | Center for Automotive Research.” http://www.cargroup.org/?module=Publications&event=View&pubID=137.

Tarbet, Marcia J. 2004. *Cost and Weight Added by the Federal Motor Vehicle Safety Standards for Model Years 1968-2001 in Passenger Cars and Light Trucks*. US Department of Transportation, National Highway Traffic Safety Administration.

Taub, Eric A. 2016. “Start-Stop Technology Is Spreading (Like It or Not).” *The New York Times*, April 7. http://www.nytimes.com/2016/04/08/automobiles/wheels/start-stop-technology-is-coming-to-cars-like-it-or-not.html.

Tavernise, Sabrina, and Robert Gebeloff. 2011. “Once Popular, Car Pools Go the Way of Hitchhiking.” *The New York Times*, January 28. http://www.nytimes.com/2011/01/29/us/29carpool.html.

Taylor, Edward, and Maria Sheahan. 2016. “Daimler Plans at Least Six Electric Car Models: Source.” *Reuters*. September 3. http://www.reuters.com/article/us-daimler-electric-idUSKCN1190EU.

Technical Assessment Report [TAR], Environmental Protection Agency [EPA], National Highway Traffic Safety Administration [NHTSA], California Air Resources Board [CARB]. 2016a. “Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025.” EPA-420-D-16-900.

Tessum, Christopher W., Jason D. Hill, and Julian D. Marshall. 2014. “Life Cycle Air Quality Impacts of Conventional and Alternative Light-Duty Transportation in the United States.” *Proceedings of the National Academy of Sciences of the United States of America* 111 (52): 18490–95.

Tews, John. 2016. “U.S. New-Vehicle Quality Makes Largest Improvement in 7 Years, J.D. Power Study Finds.” *J.D. Power*. June 22. http://www.jdpower.com/press-releases/2016-us-initial-quality-study-iqs.

Thaler, Richard H., and Cass R. Sunstein. 2008. *Nudge: Improving Decisions about Health, Wealth, and Happiness*. Yale University Press.

The Motor and Equipment Manufacturers Association, Inc. v. Environmental Protection Agency. 1979, 627 F.2d 1095. D.C. Cir.

The Perryman Group. 2014. “The Economic Benefits of Oil and Natural Gas Production: An Analysis on Effects on the United States and Major Energy-Producing States.” https://www.perrymangroup.com/wp-content/uploads/Perryman-Oil-Impact-Study.pdf.

Todd, Jennifer, Jess Chen, and Frankie Clogston. 2013. “Creating the Clean Energy Economy: Analysis of the Electric Vehicle Industry.” *International Economic Development Council, Washington, DC.*

Tomich, Jeffrey. 2016. “Ameren Seeks OK to Develop EV-Charging ‘Islands’ along I-70.” *E&E News*. August 16. http://www.eenews.net/stories/1060041642.

Traut, Elizabeth, Chris Hendrickson, Erica Klampfl, Yimin Liu, and Jeremy J. Michalek. 2012. "Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Life Cycle Greenhouse Gas Emissions and Cost." *Energy Policy* 51: 524–34.

Travers, Jim. 2015. "Pros and Cons of Aluminum Cars and Trucks - Consumer Reports." http://www.consumerreports.org/cro/news/2015/02/pros-and-cons-of-aluminum-cars-and-trucks/index.htm.

Trefis Team. 2016. "GM Electric Vehicle Plans Could Get A Big Boost With Its New Chevy Bolt EV." *Forbes*. October 20. http://www.forbes.com/sites/greatspeculations/2016/10/20/gm-electric-vehicle-plans-could-get-a-big-boost-with-its-new-chevy-volt/.

Truett, Richard. 2013. "Turbos: MPG or Muscle?" *Automotive News*. http://www.autonews.com/article/20130610/OEM06/306109977/turbos%3A-mpg-or-muscle%3F.

———. 2016a. "Diesel, Manual to Be Options on Cruze Hatchback." *Automotive News*. http://www.autonews.com/article/20161017/OEM04/310179868/diesel-manual--to-be-options-on-cruze-hatchback.

———. 2016b. "GM Plans Stop-Start Fleetwide by 2020." *Automotive News*. May 23. http://www.autonews.com/article/20160523/OEM06/305239970/gm-plans-stop-start-fleetwide-by-2020.

Turrentine, Thomas S., and Kenneth S. Kurani. 2007. "Car Buyers and Fuel Economy?" *Energy Policy* 35 (2): 1213–23.

Uhlenhuth, Karen. 2016. "State Regulators Cool to Kansas City Utility's Electric Vehicle Plans." *Midwest Energy News*. October 27. http://midwestenergynews.com/2016/10/27/state-regulators-cool-to-kansas-city-utilitys-electric-vehicle-plans/.

Undercoffler, David. 2016a. "Toyota's Fuel-Thrifty Prius Family May Shrink as Automaker Ponders Strategy." *Automotive News*. February 1. http://www.autonews.com/article/20160201/OEM05/302019971/toyotas-fuel-thrifty-prius-family-may-shrink-as-automaker-ponders.

———. 2016b. "Hydrogen Stations Increase: Will It Make a Difference?" *Autoweek*. May 31. http://autoweek.com/article/green-cars/hydrogen-stations-increase-will-it-make-difference.

———. 2016c. "Fuel-Cell Champions Still Hedge Their Bets." *Automotive News*. November. http://www.autonews.com/article/20161128/OEM05/311289913/fuel-cell-champions-still-hedge-their-bets.

Ungureanu, C. A., S. Das, and I. S. Jawahir. 2007. "Life-Cycle Cost Analysis: Aluminum versus Steel in Passenger Cars." *TMS (the Minerals, Metals & Materials Society)*. http://www.phinix.net/services/Carbon_Management/Life-cycle_Cost_Analysis.pdf.

United States Census Bureau. 2015. "Map: Median Household Income in the United States: 2015." http://www.census.gov/library/visualizations/2016/comm/cb16-158_median_hh_income_map.html.

United States Geological Survey [USGS]. 2016a. "Mineral Commodity Summaries 2016." U.S. Department of the Interior. https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf.

———. 2016b. "Mineral Commodity Summaries 2016: Aluminum." United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/aluminum/mcs-2016-alumi.pdf.

University of Michigan Transportation Research Institute [UMTRI]. 2016. "Monthly Monitoring of Vehicle Fuel Economy and Emissions." *University of Michigan*. http://www.umich.edu/~umtriswt/EDI_sales-weighted-mpg.html.

Valdes-Dapena, Peter. 2015. "Ford Aluminum Body Pickup Gets Mixed Results in Crash Test." *CNNMoney*. July 30. http://money.cnn.com/2015/07/30/autos/ford-f-150-crash-test/index.html.

Vanderwerp, Dave. 2004. "Ford Escape Hybrid 4WD." *Car and Driver*. December. http://www.caranddriver.com/reviews/ford-escape-hybrid-4wd-road-test.

Vellequette, Larry P. 2015. "Marchionne Says FCA Will Continue to Make V-8s despite Tightening Regs." *Automotive News*. September 14. http://www.autonews.com/article/20150914/OEM01/309149958/marchionne-says-fca-will-continue-to-make-v-8s-despite-tightening-regs.

Vincentric. 2014. "Hybrid Analysis October 2014." *Vincentric*. http://www.vincentric.com/Home/Industry-Reports/Hybrid-Analysis-October-2014.

———. 2015. “Canadian Hybrid Analysis.” *Vincentric*. https://www.vincentric.com/Home/Industry-Reports/Canadian-Hybrid-Analysis-January-2015.

———. 2016. “Hybrid Analysis.” *Vincentric*. http://vincentric.com/home/industry-reports/hybrid-analysis-2016.

Voelcker, John. 2016. “All-Wheel-Drive Hybrid Cars, SUVs: Why Are There so Few?” *Green Car Reports*. April 25. http://www.greencarreports.com/news/1103589_all-wheel-drive-hybrid-cars-suvs-why-are-there-so-few.

Von Kaenel, Camille. 2016. “Colorado Gives Drivers $5k When Buying Electric Cars.” *E&E News*. June 8.

Wade, Wally. Letter to John D. Graham. 2016, September 5.

Wagner, David, Paulina Nusinovich, and Esteban Plaza-Jennings. 2012. “The Effect of Proposed MY 2017-Corporate Average Fuel Economy (CAFE) Standards on the New Vehicle Market Population.” National Automobile Dealers Association (NADA).

Wald, Matthew L. 2009. “Doing the ‘Clunker’ Calculus.” *The New York Times*, August 7. http://www.nytimes.com/2009/08/08/business/08clunker.html.

Wall Street Journal. 2017. “Auto Sales.” In *Market Data Center: Calendars and Economy*. The Wall Street Journal.

Walsh, Michael P. 2011. *The Reality of Precaution – Comparing Risk Regulation in the United States and Europe*. Edited by Jonathan B Wiener, Michael D Rogers, James K Hammitt, Peter H Sand. Vol. 16. Resources for the Future.

Webb, Alysha. 2010. “California’s Zero-Emission Credits Give Startup EV Makers a Boost.” *Automotive News*. February 10. http://www.autonews.com/article/20100802/OEM01/308029992/californias-zero-emission-credits-give-startup-ev-makers-a-boost.

Weisbrod, Glen, and James Beckwith. 1992. “Measuring Economic Development Benefits for Highway Decision-Making: The Wisconsin Case.” *Transportation Quarterly* 46 (1): 57–79.

Weiss, Martin, Martin K. Patel, Martin Junginger, Adolfo Perujo, Pierre Bonnel, and Geert van Grootveld. 2012. “On the Electrification of Road Transport - Learning Rates and Price Forecasts for Hybrid-Electric and Battery-Electric Vehicles.” *Energy Policy* 48 (C). Elsevier: 374–93.

Wernle, Bradford. 2016. “NAFTA: Free Trade, with Uneven Effects.” *Automotive News*. September 19. http://www.autonews.com/article/20160919/GLOBAL/309199968/nafta%3A-free-trade-with-uneven-effects.

Wescott, Robert F., and Jeffery F. Werling. 2010. “Economic Impact of the Electrification Roadmap.” Electrification Coalition. http://keybridgedc.com/wp-content/uploads/2013/11/Keybridge-EC-Electrification-Impact-Report-Apr-2010.pdf.

White, Chris. 2016. “The Netherlands Considers Banning ALL Gas-Powered Vehicles Within 10 Years.” *The Daily Caller*. August 17. http://dailycaller.com/2016/08/17/the-netherlands-considers-banning-all-gas-powered-vehicles-within-10-years/.

White House, Office of the Press Secretary. 2012. “Obama Administration Finalizes Historic 54.5 MPG Fuel Efficiency Standards.” *White House*. August 28. https://www.whitehouse.gov/the-press-office/2012/08/28/obama-administration-finalizes-historic-545-mpg-fuel-efficiency-standard.

White, Joseph. 2016. “More Research Emerges Showing Consumers Uninformed, Wary of New Vehicle Technology.” *Automotive News*. May 26. http://www.autonews.com/article/20160526/OEM06/160529908/more-research-emerges-showing-consumers-uninformed-wary-of-new.

White, L. J. 1981a. *Reforming Regulation: Processes and Problems*. Prentice-Hall.

Williams, Mark. 2015a. “New F-150 Costs L-E-S-S to Repair.” *PickupTrucks.com News*. July 30. http://news.pickuptrucks.com/2015/07/new-f-150-costs-l-e-s-s-to-repair.html.

———. 2015b. “EPA Notes Fuel Efficiency of 2015 Ford F-150.” *PickupTrucks.com News*. August 9. http://news.pickuptrucks.com/2015/08/epa-notes-fuel-efficiency-of-2015-ford-f-150.html.

Wilson, Christopher E. 2011. “Working Together: Economic Ties between the United States and Mexico.” Mexico Institute, Woodrow Wilson International Center for Scholars.

Woodyard, Chris. 2009. “Clunkers Program Could Drive Used Car Prices up - USATODAY.com.” *USA Today*. http://usatoday30.usatoday.com/money/autos/2009-08-09-cars-cash-clunkers_N.htm.

———. 2013a. “Automakers Hawk Electric ‘Compliance Cars’ to Meet Rules.” *USA Today*, May 9. http://www.usatoday.com/story/money/cars/2013/05/09/electric-cars-compliance-cars/2144853/.

———. 2013b. “Automakers Hawk Electric ‘Compliance Cars’ to Meet Rules.” *USA Today*, May 9. http://www.usatoday.com/story/money/cars/2013/05/09/electric-cars-compliance-cars/2144853/.

———. 2015. “Nissan Leaf Shows Worst Early Resale Value.” *USA Today*, December 23. http://www.usatoday.com/story/money/cars/2015/12/23/top-10-depreciation-top-10/77796722/.

———. 2016a. “More Drivers Falling behind on Their Car Payments.” *USA Today*, February 10. http://www.usatoday.com/story/money/cars/2016/02/09/more-drivers-falling-behind-their-car-payments/80058164/.

———. 2016b. “Spunky Nissan Leaf a Contender.” *USA Today*. September 23.

———. 2016c. “Review: Nissan Leaf Now Goes Farther -- but Needs More.” *USA Today*, September 24. http://www.usatoday.com/story/money/cars/2016/09/24/review-nissan-leaf-2016-test-drive/90835700/.

Woodyard, Chris, and Fred Maier. 2011. “Lexus, Honda Top Power Quality Study; Ford Slips - USATODAY.com.” *USA Today*, June 23. http://www.usatoday.com/MONEY/usaedition/2011-06-24-driveon24_ST_U.htm.

Yan, Sophia. 2015. “China Is about to Tighten Its Grip on Rare Earth Minerals.” *CNN*. June 5. http://money.cnn.com/2015/06/05/investing/molycorp-china-rare-earth-minerals/index.html.

Yergin, Daniel. 2011. *The Quest: Energy, Security, and the Remaking of the Modern World*. New York: Penguin Books.

Young, Angelo. 2014. “Auto Industry Contribution To US GDP Is Way Up From 2011, When Fears Of Double-Dip Recession Made Consumers Wary.” *International Business Times*. July 30. http://www.ibtimes.com/auto-industry-contribution-us-gdp-way-2011-when-fears-double-dip-recession-made-1643732.

———. 2015. “Is The ‘Chicken Tax’ On The Chopping Block? Trade Deals Could See More Small Pickups In US Market If Import Tariff Is Lifted.” *International Business Times*. June 29. http://www.ibtimes.com/chicken-tax-chopping-block-trade-deals-could-see-more-small-pickups-us-market-if-1988363.