# Effects of the Draft CAFE Standard Rule on Vehicle Safety

Final report

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# EXECUTIVE SUMMARY

The U.S. Department of Transportation (DOT) and U.S. Environmental Protection Agency (EPA) have proposed the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule to replace the existing and augural fuel economy and existing greenhouse gas (GHG) standards for light-duty vehicles set in place in 2012 for Model Years (MY) 2017-2025.[1] The draft rule proposes a rollback of the current, more stringent standards for vehicles in model years of 2021 through 2026 by holding the standards at 2020 levels through 2026. Consistent with the rule's name (SAFE Vehicles Rule), the National Highway Traffic Safety Administration (NHTSA) and EPA estimate that the proposed rule will reduce traffic-related fatalities.

Consumers Union commissioned Synapse Energy Economics (Synapse) to examine NHTSA's and EPA's sales and safety analysis, which is presented as a primary motivation for the selection of the standards in the draft rule. NHTSA and EPA estimate that lighter vehicles lead to more vehicle crash fatalities and automakers will be less inclined to reduce the mass of their vehicles if fuel economy standards are less stringent. Further, the agencies indicate that newer vehicles are safer, and more people will buy new vehicles under the draft rule instead of holding onto older vehicles because the cost to buy a new vehicle will be lower.

**Key Findings**

Synapse's research finds serious flaws in the arguments and underlying analysis and assumptions used by NHTSA and EPA. After correcting these flaws, Synapse's analysis shows that increasing fuel economy and GHG standards maintains or even improves vehicle safety, consistent with peer-reviewed literature on this topic and past agency findings.

- There are many technologies and techniques that automakers use to achieve fuel economy standards that have no influence on or even improve vehicle safety (e.g. more efficient engines and transmissions, reducing engine idling, and improved aerodynamics).
- With respect to reducing vehicle mass, new high-strength lightweight materials are already available in a subset of the fleet and can maintain or improve vehicle safety as they are used more broadly.
- The adoption of new technologies and practices has made new vehicles safer over time. However, behavioral and demographic characteristics have by far the largest influence on fatality statistics, which the agencies do not account for. As a result, the agencies overstate the magnitude of the safety benefit of newer vehicles.
- Most importantly, the agencies also miscalculate the direction of the effect of standards on sales. Once fuel savings are properly accounted for and erroneous cost and rebound

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[1] NHTSA and EPA. The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks, p. 42,989. https://www.gpo.gov/fdsys/pkg/FR-2018-08-24/pdf/2018-16820.pdf.

effect assumptions are corrected, more efficient cars and trucks have a lower total cost of ownership. As a result, vehicle sales are likely to increase (not decrease) with stronger standards. Our scenarios with corrected compliance cost and rebound effect assumptions show a growth of cumulative vehicle sales (model years 2017-2029) of more than 500,000 under the augural standards relative to the draft rule.

- Because the agencies err in both the magnitude and the direction of the influence of changes to vehicle sales that might result from changing the standards, their estimates of fatalities avoided and vehicle sales cannot be correct. Our sales and safety analyses suggest that the draft rule will reduce vehicle sales and will therefore result in a less safe fleet.[2] Therefore, the draft rule will likely increase fatalities rather than avoid them.

As a result of these findings, Synapse recommends that NHTSA and EPA should: (1) account for both purchase price and fuel spending in their modeling of the total cost of ownership and (2) apply more accurate assumptions for compliance costs, fuel spending, and rebound effects in their modeling. When these corrections are made, the agencies are likely to find that weakening standards does not increase vehicle sales nor reduce fatalities. Instead, the draft rule will likely depress vehicle sales and increase fatalities. We note that our analysis did not evaluate all sources of potential errors in the NRM, such as those related to scrappage.

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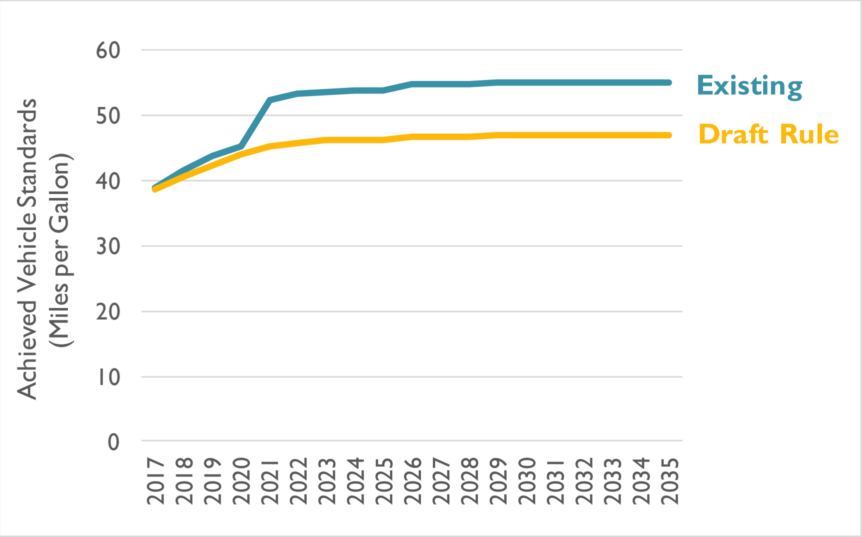
[2] Synapse did not review all potential sources of errors and flaws in NHTSA's and EPA's investigation. For example, Synapse did not review the scrappage modeling done by NHTSA and EPA.

# 1. INTRODUCTION

On August 2, 2018, the U.S. Department of Transportation (DOT) and U.S. Environmental Protection Agency (EPA) proposed the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule.[3] The draft rule proposes to roll back the existing Corporate Average Fuel Economy and tailpipe greenhouse gas emissions standards (CAFE/GHG standards) for passenger cars and light trucks for model years 2021 through 2026 by holding the standards constant at 2020 levels from 2020 on. The existing CAFE/GHG standards, set in 2012, feature fuel economy targets that grow to an average new vehicle fuel economy of approximately 36 miles per gallon for model year 2025 vehicles.[4] Parties were asked to provide comment on the draft rule over a period of 60 days following official publication in the Federal Register on Friday, August 24, 2018.

Figure 1 and Figure 2 show the existing achieved vehicle standards of cars and trucks compared to the draft rule.

**Figure 1. Achieved Vehicle Standards of Cars**



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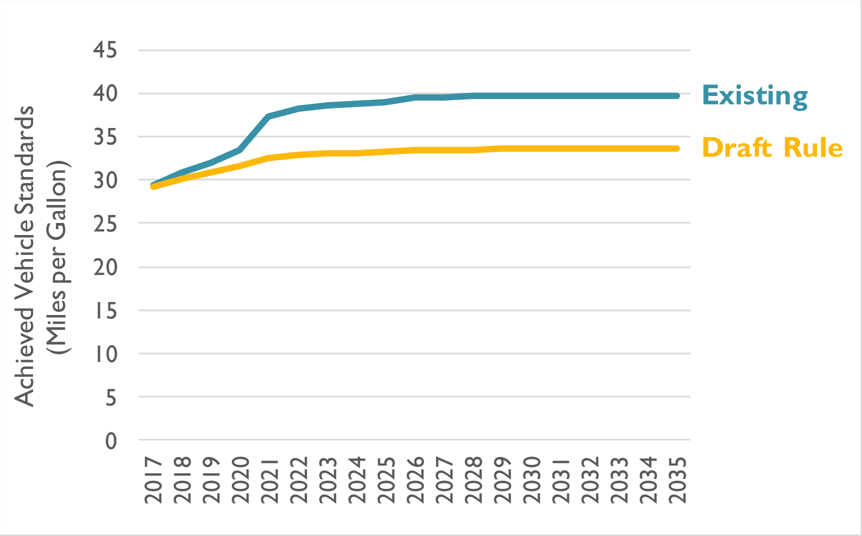
[3] NHTSA and EPA. The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks, p. 42,989. https://www.gpo.gov/fdsys/pkg/FR-2018-08-24/pdf/2018-16820.pdf.

[4] EPA. Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicles Greenhouse Gas Emissions Standards under the Midterm Evaluation, p. 5. January 2017. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100QQ91.pdf.

**Figure 2. Achieved Vehicle Standards of Light Trucks**



The National Highway Traffic Safety Administration (NHTSA) and EPA estimate that the draft rule would "reduce highway fatalities by 12,700 lives" when compared to the existing standards.[5] NHTSA and EPA provide the following key arguments to support their estimate that the draft rule saves lives:

- Lighter vehicles lead to more vehicle crash fatalities and automakers will be less inclined to reduce the mass of vehicles if fuel economy standards are less stringent.
- Newer vehicles are safer, and more people will buy a new vehicle instead of holding onto an older vehicle because the cost of a new vehicle will be lower under the draft rule.

Consumers Union retained Synapse Energy Economics, Inc. (Synapse) to investigate the safety arguments supporting the draft rule.[6] Synapse conducted a literature review and reviewed NHTSA's and EPA's sales and safety modeling.

- Synapse's literature review finds that when applied sensibly, mass reductions can be safety-neutral or better. In fact, the use of new high-strength lightweight materials can simultaneously offer more protection, reduce mass, and increase fuel economy.
- While it is true that newer vehicles are safer due to improvements in safety technology, Synapse's investigation of the underlying assumptions and analysis supporting NHTSA and EPA's sales and safety-related arguments identified several significant errors. When these errors are corrected, the total cost of ownership is lower for more efficient vehicles. The review and analysis find that increasing fuel economy and GHG standards

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[5] See the announcement of the proposed rule at: https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy.

[6] Synapse did not review the scrappage modeling done by NHTSA and EPA in its investigation.

maintains or even improves vehicle safety This is because more efficient cars and trucks can have a lower total cost of ownership which could increase vehicle fleet turnover.

The purpose of this report is to recommend changes to NHTSA's and EPA's assumptions and approach and to provide a more accurate discussion of the relationship between improved fuel economy standards and safety. Section 2 provides a discussion of overall fuel economy and safety trends based on the literature review. Section 3 explains the different approaches to increasing fuel economy and effects on safety, also based on the literature review. Section 4 investigates the key factors affecting vehicle safety. Section 5 assesses NHTSA's and EPA's sales and safety modeling. Section 6 discusses opportunities for additional research. Section 7 presents recommendations and conclusions. The appendices in Section 8 provide more detailed information on the results and a list of references.

# 2. FUEL ECONOMY AND SAFETY TRENDS

Vehicle fuel economy and safety have both improved since 1975. Each year the EPA publishes a report examining the trends in carbon dioxide ($CO_2$) emissions, fuel economy, and technology in the automotive industry. This Trends Report uses fleet-wide data obtained directly from automobile manufacturers for model years 1975 to 2017.[7,8] The January 2018 Trends Report shows that adjusted fuel economy has increased from 13.1 miles per gallon (mpg) for MY 1975 to an estimated 25.2 mpg for MY 2017 vehicles.[9]

Figure 3 below shows that average fuel economy has more than doubled between MY 1975 and 2016. Historically, there was a rapid improvement in fuel economy from MY 1975 to MY 1981 followed by slower improvements between MY 1982 and MY 1987. There was a steady reversal of these improvements from MY 1988 through MY 2004 as the share of trucks increased. Beginning in MY 2005, fuel economy began to rise again and did so in 10 of the 12 individual years, as well as on average over the period.

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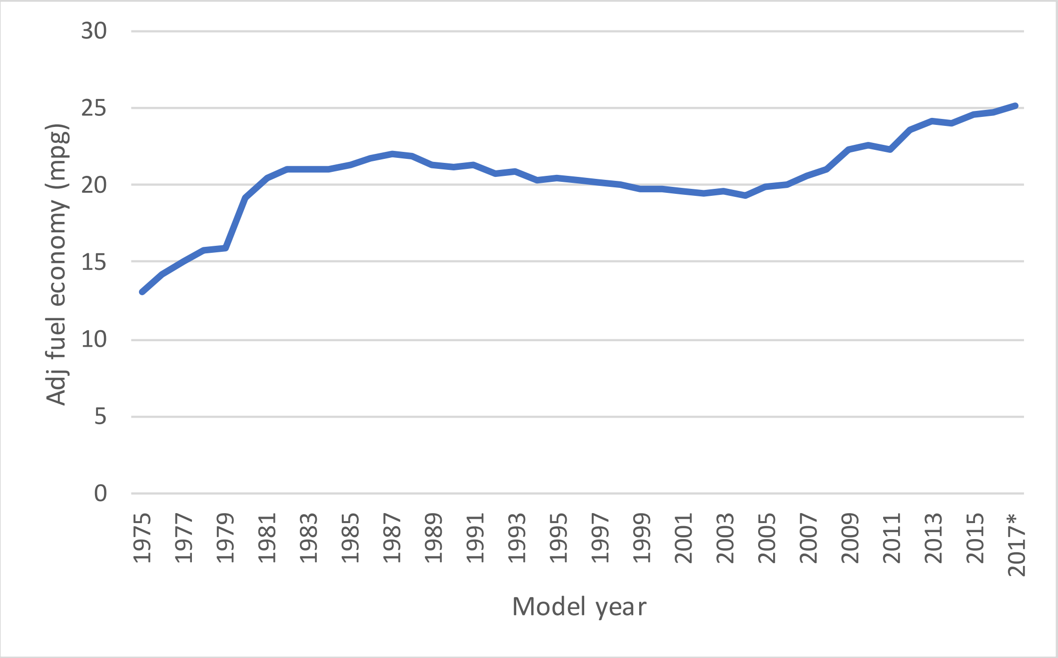
[7] Based on a production-weighted analysis of new vehicles produced for the U.S. fleet.

[8] Note that data for MY 2017 are preliminary.

[9] U.S. Environmental Protection Agency. 2018. "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2017." EPA-420-R-18-001. Page 4.

**Figure 3. Change in adjusted fuel economy since 1975**



*Source: Data are from: US Environmental Protection Agency. 2018. "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2017." EPA-420-R-18-001. Page 4.*

EPA observed decreases in vehicle weight of 1.9 percent between MY 2004 and MY 2016. While these decreases were expected to increase fuel economy, the overall increase was far more than would be expected from mass reductions alone: fuel economy increased 28 percent or 5.4 mpg.[10]

Vehicle safety has also improved over time. NHTSA data from its Fatality Analysis Reporting System (FARS) [11] show that the annual number of crash fatalities has declined between 1975 and 2016, despite steady growth in the population.[12] The rate of death per 100,000 people has also declined, going from a rate of 20.6 in 1975 to 11.6 in 2016.[13] Those trends are shown in Figure 2.

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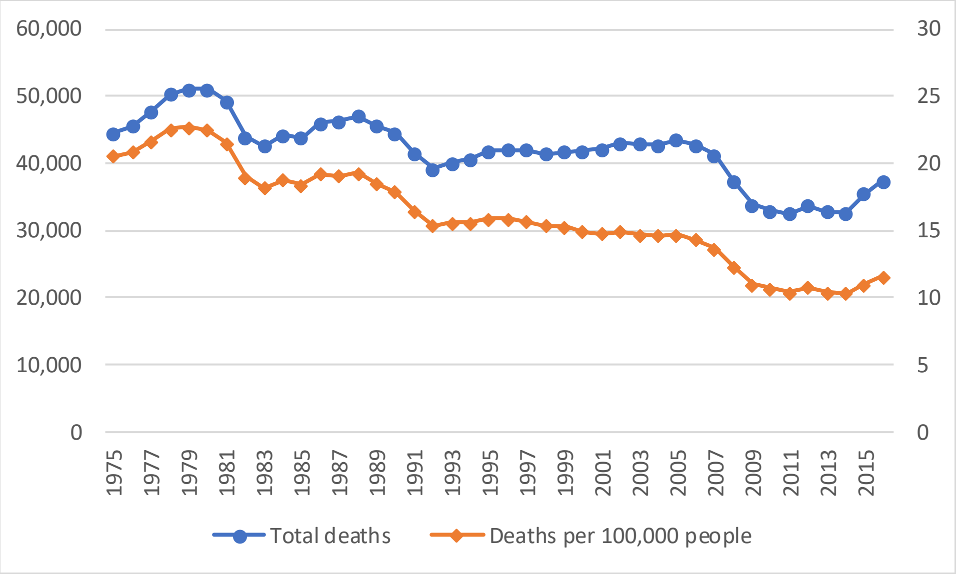
[10] U.S. Environmental Protection Agency. 2018. "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2017." EPA-420-R-18-001. Page 8.

[11] FARS contains data from the 50 states, the District of Columbia, and Puerto Rico.

[12] See the Insurance Institute for Highway Safety, General Statistics. Available at: https://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/overview-of-fatality-facts

[13] 2015 and 2016 saw an uptick in fatalities due to increases in crashes attributed to drunk driving, speeding, failure to use a seatbelt and driver age (over 65 years old). All of these causes are unrelated to the crashworthiness of the vehicles themselves. See Isidore, C. (2017, October 6). Despite Safer Cars, Traffic Fatalities are on the Rise [CNNMoney.com article]. https://money.cnn.com/2017/10/06/autos/fatal-traffic-accidents/index.html.

**Figure 4. Motor vehicle crash deaths and deaths per 100,000 people, 1975-2016**



*Source: Data are from See the Insurance Institute for Highway Safety, General Statistics. Available at: https://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/overview-of-fatality-facts*

Vehicle safety improvements over the past four decades for all weight and size classes is largely due to technological advances.[14] Front and side airbags, improvements to structural integrity, and other measures help protect vehicle occupants. Crash avoidance technologies like improved braking systems and electronic stability control reduce the likelihood of a crash and the severity of collisions that do occur. Advanced driver assistance systems, which can provide automated crash warning and safety interventions, are becoming more prevalent and may help prevent crashes or mitigate fatalities in crashes.

Research shows that these safety improvements decrease the likelihood of driver death in a crash. A 2015 study from the Insurance Institute for Highway Safety (IIHS) examined the historical effects of vehicle design changes on driver fatality rates.[15] Researchers compared actual driver deaths to expected deaths in vehicles with no design changes and found that advanced safety design and a changing vehicle mix have contributed to the decline in motor vehicle fatality risk for all vehicle types since the mid-1990s. Had vehicles remained the same as in 1985, there would have been 7,700 more driver deaths in 2012.[16] IIHS found that by MY 2009, the fatality risk for car drivers declined 51 percent from its peak in

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[14] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration. 2012. “2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards.” Federal Register 77.199. Page 122.

[15] Farmer, Charles M. and Adrian K. Lund. “The Effects of Vehicle Redesign on the Risk of Driver Death.” *Traffic Injury Prevention* 16 (2015): 684-690.

[16] Ibid. Page 685.

MY 1994, the fatality risk for drivers of pickup trucks declined 61 percent from its high in MY 1988, and the fatality risk for drivers of SUVs declined 79 percent from its high in MY 1988.[17]

Other factors have also contributed to a decreased fatality rate over time. For example, a 2015 NHTSA study examined the effectiveness of vehicle safety technologies at reducing fatality risk between 1960 and 2012.[18] Authors focused on the fatality risk reduction attributable to vehicle safety improvements introduced since 1956, including factory-installed lap belts and vehicle safety improvements associated with the Federal Motor Vehicle Safety Standards from 1968 onwards. The agency estimated that 613,501 lives were saved between 1960 and 2012 because of at least four factors, including:

1. Improvements in vehicle safety due to the installation of seat belts, air bags, and electronic stability control, along with programs to increase driver use of such equipment;
2. Improvements to existing roads and major new infrastructure (e.g., the Interstate Highway System) making roads safer for drivers;
3. Laws and programs to decrease the incidences of drunk driving, along with other behavioral programs to help people adopt safer driving habits; and
4. Faster and improved medical care after a vehicle crash, including quicker arrival of emergency services and more effective treatment both in transport and upon arrival at a medical center.

Historical data show that safety and fuel economy have improved in tandem. Automakers can achieve further improvements to fuel economy in several ways, including the introduction of additional new vehicle technologies and mass reduction, particularly in the heaviest vehicles. If properly implemented, these methods aimed at increasing fuel efficiency can also improve safety.

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[17] Ibid. Page 689.

[18] Kahane, C. J. 2015. “Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes.” (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration.

# 3. APPROACHES TO INCREASE FUEL ECONOMY AND THEIR EFFECTS ON SAFETY

Automakers have the flexibility to comply with CAFE standards through several different pathways, which include mass reduction and the integration of new technologies that improve vehicle efficiency.[19]

## 3.1. Technological improvement

There are several new and developing technologies that can improve fuel economy. These include (1) improvements in engines, including downsized turbocharged engines, variable compression ratio engines, homogenous charge compression ignition engines, gasoline direct injection, cylinder deactivation, and non-hybrid stop/start; (2) improvements to transmissions, including continuously variable transmissions and transmissions with seven or more gears; (3) better aerodynamics; (4) more energy efficient drive accessories (e.g., power steering); (5) more energy efficient air conditioning systems; and, (6) lower rolling resistance tires.[20]

In 2016, EPA and NHTSA projected that automakers could comply with MY 2025 CAFE/GHG standards using the following pathways, as shown in Table 1 below.

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[19] U.S. Environmental Protection Agency. 2017. "Final Determination on the Appropriateness of the Model Year 2022–2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards Under the Midterm Evaluation." EPA-420-R-17-001.

[20] U.S. Environmental Protection Agency. 2018. "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2017." EPA-420-R-18-001. Page 47.

**Table 1. Selected fleet-wide penetrations to meet MY2025 standards**

| | GHG | CAFE |
|---|---|---|
| Turbocharged and downsized gasoline engines | 33% | 54% |
| Higher compression ratio, naturally aspirated gasoline engines | 44% | <1% |
| 8-speed and other advanced transmissions | 90% | 70% |
| Mass reduction | 7% | 6% |
| Stop-start | 20% | 38% |
| Mild hybrid | 18% | 14% |
| Full hybrid | <3% | 14% |
| Plug-in hybrid electric vehicle | <2% | <1% |
| Electric vehicle | <3% | <2% |

*Note: Reproduced from United States Environmental Protection Agency, National Highway Traffic Safety Administration, and California Air Resources Board. 2016. "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-16-901.*

In its 2016 *Draft Technical Assessment Report* for the MY 2022-2025 CAFE/GHG standards, EPA found that a wider range of technologies had become available to meet the standards, at a similar or lower cost, than what was projected in the 2012 rule. Advanced gasoline vehicle technologies dominated the mix.[21]

Of the many technological approaches to improving fuel economy, most have no effect on vehicle safety. In fact, if done correctly, some of these pathways can improve vehicle safety.

## 3.2. Mass reduction

Mass reduction refers to a reduction in total vehicle mass or weight. Automakers can reduce the mass of vehicles by using lighter materials or reducing the size of vehicles. Early research assumed that vehicle weight and size (or "footprint" — the product of wheelbase times average track width, or the area between where the centers of the tires touch the ground) were not independent and thus have the same effect on safety and fatality risk.[22] For example, a 2001 study published by the National Academy of Sciences, researchers recommended tying fuel economy to vehicle weight to disincentivize

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[21] U.S. Environmental Protection Agency. 2016. "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-16-901.

[22] Ibid. Page 8-4.

manufacturers from selling lighter cars to offset sales of heavier cars and meet fleet-wide targets.[23] However, both the vehicle fleet and fuel economy standards have changed significantly since this time, and more recent research demonstrates that reducing mass while maintaining vehicle footprint can be safety-neutral, or even safety positive.

In 2005, Van Auken and Zellner of Dynamic Research, Inc. performed a statistical analysis of MY 1985 to MY 1998 passenger cars and MY 1985 to MY 1997 light trucks and vans involved in traffic crashes between 1995 and 1999. The authors concluded that (1) reductions in vehicle mass would decrease the number of traffic fatalities; (2) reductions in vehicle wheelbase and/or track width would increase the number of traffic fatalities; and (3) across-the-board reductions in both vehicle mass and footprint would have little, if any, effect on traffic fatalities because these variables have opposite effects that negate each other.[24]

These findings led modern CAFE/GHG standards to be based on vehicle footprint to disincentivize downsizing while encouraging mass reductions in the heaviest vehicles, thus improving safety. In 2009, NHTSA developed a footprint-based standard to create a disincentive for manufacturers to produce smaller-footprint vehicles—as the footprint decreases, the fuel economy target becomes more stringent. NHTSA also varied the fuel economy improvements required of the smallest and largest vehicles to encourage automakers to shed mass from the heaviest vehicles while discouraging doing so for the smallest.[25] The MY 2017–2025 CAFE rulemaking continues to utilize this footprint-based standard. In 2015, the National Academy released a second study concluding that the change to a footprint-based standard had alleviated many safety concerns, stating: “An important motivation for adopting a standard based on vehicle footprint… is to be safety-neutral. The committee found the empirical evidence from historical data appears to support the argument that the new footprint-based standards are likely to have little effect on vehicle and overall highway safety.”[26]

Bento, et al. suggest in their 2017 study that CAFE standards would decrease the number of crash fatalities even more if the heaviest vehicles were down-weighted and the weight disparity across the fleet were reduced.[27] The authors found that heavier vehicles are safer for their own occupants but more hazardous for the occupants of other vehicles. Thus, there may be a higher number of fatalities in certain vehicles if those (already lighter) vehicles reduce their weight, but total fatalities would be lower

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[23] National Research Council. 2002. “Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards.” National Academy of Sciences.

[24] Van Auken, R.M. and J.W. Zellner. “An Assessment of the Effects of Vehicle Weight and Size on Fatality Risk in 1985 to 1998 Model Year Passenger Cars and 1985 to 1997 Model Year Light Trucks and Vans,” SAE Technical Paper 2005-01-1354, 2005.

[25] National Highway Traffic Safety Administration. 2009. “Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks: Final Regulatory Impact Analysis.”

[26] National Research Council. 2015. “Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light Duty Vehicles.” National Academy of Sciences.

[27] Bento, et al. 2017. “The Effect of Fuel Economy Standards on Vehicle Weight Dispersion and Accident Fatalities.” National Bureau of Economic Research. Working Paper 23340.

if *all* vehicles reduce their weight (this is the "arms race" metaphor" of vehicle mass reduction).[28] If weight were taken from the heaviest vehicles in the fleet, it would reduce the likelihood of crashes involving vehicles of substantially different weights, increasing the overall safety of the vehicle fleet. Russ Rader, a spokesman for IIHS, said that the organization was supportive of a footprint-based standard, stating that "… using a sliding scale for fuel economy improvements by vehicle footprint, addressed safety concerns that IIHS raised in the past."[29] Lawrence Berkeley National Laboratory (LBNL) compared NHTSA studies done between 2003 and 2018, finding that if mass is reduced while footprint is held constant, the fatality risk decreases compared to instances where both mass and footprint are reduced simultaneously.[30] Indeed, elsewhere in NHTSA and EPA's own studies, the agencies note, "Because each vehicle model has its own target (determined by a size-related attribute), properly fitted attribute-based standards provide little, if any, incentive to build smaller vehicles simply to meet a fleet-wide average, because smaller vehicles are subject to more stringent compliance targets."[31]

Vehicle design plays an important role with respect to safety, as demonstrated in Tom Wenzel's 2018 analysis that examines the relationship between vehicle mass, size, and safety. Wenzel's research shows the estimated effect of mass or footprint reduction on fatality risk per vehicle mile traveled (VMT) in the United States. After excluding certain car models, the regressions indicate that the results are sensitive to which car models are included. This suggests that design of specific models is an important variable. The regression that includes all-wheel drive cars but excludes two high risk sport car models results in much lower fatality risk for lighter than average cars (from a 1.20 percent increase to a 0.94 percent increase). Another regression that just excludes two high risk sport cars results in much lower fatality risk for lighter cars (from (from a 1.20 percent increase to a 1.11 percent increase) and heavier cars (from a 0.42 percent increase to a 0.25 percent increase).[32]

A specific improvement to vehicle design might include, for example, the use of lightweight materials that are higher-strength. These materials are readily available and can maintain, or even improve, occupant safety while reducing weight. Ford Motor Company redesigned its MY 2015 F-150 pickup truck using a military-grade aluminum alloy body instead of steel. The lighter aluminum alloy made it possible for Ford to make the body thicker for improved strength while reducing vehicle weight by up to 700 pounds and improving fuel economy.[33]

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[28] Bento, 2017.

[29] Beene, Ryan and John Lippert. 2018. "Safety Gains from Heavier Cars may be Cited to Cut MPG Rules." Bloomberg.

[30] Wenzel, Tom. 2018. "Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2004-2011 Passenger Cars and LTVs' (LBNL Phase 1)." Table 5-8. Lawrence Berkeley National Laboratory.

[31] NPRM at 43016

[32] Wenzel, Tom. 2018. "Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2004-2011 Passenger Cars and LTVs' (LBNL Phase 1)." Lawrence Berkeley National Laboratory. Page 75.

[33] Ford Motor Company. "Body of Work." Accessed July 26, 2018. Available at: https://corporate.ford.com/innovation/f-150-body-of-work.html.

Ford is one example of an automakers that has taken an important step in reducing mass in one of its heavier vehicles, which has a net societal benefit. Where previous literature focused only on the mean weights of vehicles,[34] more recent research has demonstrated that both mean weight and the disparity in weight between the vehicles involved in two-vehicle crashes play a role in fatalities.[35] Mass reduction in heavier vehicles can therefore reduce the disparity in weight between vehicles involved in crashes, potentially helping to save lives.

Safety may be affected in part on the specific vehicles that are down-weighted. As noted by EPA and NHTSA in the *Federal Register*, when two vehicles of unequal mass collide, the change in velocity is higher in the lighter vehicle, which can increase fatality risk.[36] Thus, removing mass from the heavier vehicle would reduce the lighter car's change in velocity and decrease the fatality risk.[37] NHTSA's 2016 analysis of MY 2003-2010 cars and light transportation vehicles (LTVs) in calendar year (CY) 2005-2011 crashes examined the fatality increase per 100-pound mass reduction while holding footprint constant. NHTSA found that none of the estimated risk effects were statistically significant at the 95 percent confidence interval. Only three were significant at the 90 percent level—the 1.49 percent risk increase in lighter cars, the 0.72 percent risk decrease in the heavier LTVs, and the .99 percent risk decrease in crossover utility vehicles (CUVs) and minivans.[38] NHTSA states that "[b]ased on these results, potential combinations of mass reductions that maintain footprint and are proportionally somewhat higher for the heavier vehicles may be safety neutral or better as point estimates and, in any case, unlikely to significantly increase fatalities."[39] In summary, removing weight from the heaviest vehicles in the fleet—while maintaining size—may improve the overall safety of the fleet, creating a net societal benefit.

## 3.3. Findings

There are several different approaches that manufacturers might take to improve fuel economy. The majority of those are technology-related, including improvements to engines and transmissions. Safety is often enhanced by using these new technologies.

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[34] See, for example: Crandall, Robert W., and John D. Graham. 1989. "The Impact of Fuel Economy Standards on Automobile Safety." *The Journal of Law and Economics*. 32 (1):97-118. See also: Noland, Robert B. 2004. "Motor Vehicle Fuel Efficiency and Traffic Fatalities." *The Energy Journal*. 25 (4)1-22.

[35] See, for example: Anderson, Michael L. and Maximilian Auffhammer. 2014. "Pounds that Kill: The External costs of Vehicle Weight." *The Review of Economic Studies*. 81 (2):535-571.

[36] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration. 2012. "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards." Federal Register 77.199.

[37] Id.

[38] Puckett, S.M. and Kindelberger, J.C. 2016. "Relationships between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs – Preliminary Report. (Docket No. NHTSA-2016-0068). Washington, DC: National Highway Traffic Safety Administration.

[39] Ibid. See Abstract.

Mass reductions that both maintain vehicle footprint and are proportionately higher for heavier vehicles may be safety-neutral or better. Also, the use of new higher-strength lightweight materials can improve occupant protection while reducing weight and increasing fuel efficiency.

# 4. KEY FACTORS AFFECTING VEHICLE SAFETY

## 4.1. Existing Research and Data Sources

Synapse reviewed existing literature on vehicle safety, model year, and mass reduction, including reports by leading researchers Charles J. Kahane, formerly of NHTSA, and Tom Wenzel of LBNL conducted between 2012 and 2018. Kahane's recent research focuses on the effects of vehicle mass reduction on safety, with specific focus on differences between cars and trucks of different weights and sizes and societal level effects (that is, the risk of fatality to occupants in the case vehicle as well as any crash partners, including pedestrians and cyclists) when these effects are aggregated at the fleet level. Kahane 2012 found that societal fatality risk increases only slightly, 1.56 percent, for each mass reduction of 100 pounds in lighter cars (that is, cars less than 3,106 pounds) while holding vehicle size constant. The effect was found to be statistically significant at the 95 percent confidence interval. This effect has been decreasing over time, as the analysis has been updated with newer vehicles.[40] Kahane 2012 found no other statistically significant increases in societal fatality risk for mass reduction in other types of cars but finds non-statistically significant decreases in societal fatality risk for mass reduction in CUV/minivans and heavier trucks.[41] The Kahane 2012 findings are provided in Table 2 below. To summarize, the results show that mass reduction has a statistically significant effect only on fatality rates in lighter cars. A more recent study by Puckett and Kindelberger (2016) finds that mass reduction does not have a statistically significant effect on fatality rates in any vehicle type at the 95 percent confidence level.[42] The Puckett and Kindelberger findings are also provided in Table 2 below.

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[40] Wenzel, Tom. 2018. "Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2004-2011 Passenger Cars and LTVs' (LBNL Phase 1)." Lawrence Berkeley National Laboratory. Figure 2.9.

[41] Kahane, C. J. 2012. "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Final Report." (Report No. DOT HS 811 665). Washington, DC: National Highway Traffic Safety Administration.

[42] Puckett, S.M. and Kindelberger, J.C. 2016. "Relationships between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs – Preliminary Report. (Docket No. NHTSA-2016-0068). Washington, DC: National Highway Traffic Safety Administration.

**Table 2. Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint Constant**

| Kahane 2012 | | |
|---|---|---|
| **MY 2000-2007<br>CY 2002-2008** | **Point Estimate** | **95% Confidence Bounds** |
| Cars < 3,106 pounds | 1.56 | +0.39 to +2.73 |
| Cars >= 3,106 pounds | 0.51 | -0.59 to +1.60 |
| CUVs and minivans | -0.37 | -1.55 to +0.81 |
| Truck-based LTVs < 4,594 pounds | 0.52 | -0.45 to +1.48 |
| Truck-base LTVs >= 4,594 pounds | -0.34 | -0.97 to +0.30 |
| **Puckett and Kindelberger 2016** | | |
| **MY 2003-2010<br>CY 2005-2011** | **Point Estimate** | **95% Confidence Bounds** |
| Cars < 3,197 pounds | 1.49 | -0.30 to +3.27 |
| Cars >= 3,197 pounds | 0.50 | -0.59 to +1.60 |
| CUVs and minivans | -0.99 | -2.17 to +0.19 |
| Truck-based LTVs < 4,947 pounds | -0.10 | -1.08 to +0.88 |
| Truck-based LTVs >= 4,947 pounds | -0.72 | -1.45 to +0.02 |

*Source: Puckett, 2016, p. xii.*

The decrease in societal fatality risk from mass reduction in heavier light trucks has been increasing over time as the analysis has been updated.[43] Wenzel's research replicates NHTSA studies and finds that the estimated effect of mass or footprint reduction on vehicle risk is much smaller than the estimated effects of other control variables, such as driver gender, crash conditions, and the presence of specific safety technologies. Wenzel finds that, "Many of the control variables NHTSA includes in its logistic regressions are statistically significant and have a much larger estimated effect on fatality risk than vehicle mass. For example, installing torso side airbags, electronic stability control, or an assisted braking system in a car is estimated to reduce fatality risk by about 7% to 16%; cars driven by men are estimated to have a 37% higher fatality risk than cars driven by women; and cars driven at night, on rural roads, or on roads with a speed limit higher than 55 mph are estimated to have a fatality risk over twice that of cars driven during the daytime on low-speed non-rural roads. The relatively small estimated effects of mass reduction are overwhelmed by these other vehicle, driver and crash factors."[44]

In addition, Wenzel analyzed the relationship between fatality risk and mass by vehicle model, finding that, "…(A)fter accounting for the many vehicle, driver, and crash variables NHTSA used in its regression

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[43] Wenzel, Tom. 2018. "Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2004-2011 Passenger Cars and LTVs' (LBNL Phase 1)." Lawrence Berkeley National Laboratory. Figure 2.9.

[44] *Ibid*. Executive Summary.

analyses, there remains a wide variation in risk by vehicle make and model, and this variation is unrelated to vehicle mass."[45]

Several of the best sources of vehicle safety data include:

- NHTSA's FARS dataset. This dataset provides data for traffic crashes between years 1982 and 2016, with variables including: the age and gender of the drivers, the type of vehicles involved in the crash, as well as the time and location of the crash.

- NHTSA's induced-exposure crash datasets for 13 states. These datasets include information on the non-culpable drivers in nonfatal crashes. Because the data focus on the non-culpable drivers, they speak to the exposure of vehicle and demographic types, as they capture the frequency in which various vehicles and driver demographics were hit by other vehicles.

- R. L. Polk's National Vehicle Population Profiles (NVPP) dataset. These data provide national and state-level vehicle registration data by vehicle make, model, and model year.

- Carfax average odometer readings. These data provide average odometer readings from various sources and are used to provide annual VMT estimates by vehicle make, model, and model year.

NHTSA's FARS dataset was used to evaluate the accuracy of NHTSA's findings on the effect of new vehicles on fleet-wide vehicle safety. Kahane's and Wenzel's research informed the development of additional regression models to identify the extent to which model year influences vehicle safety.

## 4.2. Methodology

In a research note published by NHTSA, the authors present results from a descriptive assessment of the relationship between a vehicle's age and model year to an occupant's injury severity in a fatal crash.[46,47,48] The authors use 2012–2016 data from NHTSA's FARS dataset and find "a consistent pattern that the percentage of occupants [that were] fatally injured was higher among occupants of older model year vehicles than those of newer model year vehicles in every age group examine(d)."[49] The analysis

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[45] Wenzel, Tom. 2016. "Assessment of NHTSA's Report 'Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs." Lawrence Berkeley National Laboratory. Figures 4.7 (3 vehicle types), Figures 4.9 and 4.13, and Table 4.2 (3 and 7 vehicle types).

[46] Please note that model year includes new technologies and practices that cannot be assessed independently.

[47] The dependent variable can also be described as the fraction of vehicle occupants that do not survive a crash. We note that the dependent variable is likely to increase as the number of occupants decrease. We continue to use this dependent variable in our regression analysis for consistency with the NHTSA analysis.

[48] National Highway Traffic Safety Administration. 2018. *Passenger Vehicle Occupant Injury Severity by Vehicle Age and Model Year in Fatal Crashes.* Traffic Safety Facts: Research Note. DOT HS 812 528.

[49] NHTSA (2018), p. 1.

suggests that newer model year vehicles are getting continuously safer (where safety is defined as the percentage of occupants fatally injured in a fatal crash). But, the authors note that the analysis should be expanded to include a statistical analysis of the relationship between fatality risk, vehicle age, model year, and additional control variables, including use of a restraint system, age, change in velocity (Delta-V), and sex of the driver.

Synapse recreated and expanded on NHTSA's multivariate regression analysis using the most recently released FARS data for 2000 through 2016 to confirm the finding that newer model years were safer. As suggested by the NHTSA researchers, this analysis was expanded to include additional demographic and behavioral variables. Also included are a variable for calendar year to capture driving trends over time, as well as a binary variable used to capture crashes that happen in states with above-average crash fatality rates. The inclusion of the high fatality state binary variable was informed by Kahane and Wenzel's research.[50,51] The table below provides the categories and names of the variables included in the analysis and a description of each one.[52]

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[50] Kahane, August 2012, p. 28.

[51] Wenzel, 2018, p. 6.

[52] Note that changes in vehicle mix are not addressed in this research.

**Table 3. Multivariate Regression Variables**

| Variable | Variable Category | Variable Name | Variable Type | Variable Description |
|---|---|---|---|---|
| **1** | Dependent | Vehicle Fatalities | Pct | Number of fatalities in a vehicle as a percent of vehicle occupancy |
| **1** | Independent, Manufactured | Model Year | Numeric | Represents the manufacturer's model year of the vehicle |
| **2** | Independent, Behavioral | Calendar Year | Numeric | The calendar year in which the accident occurred |
| **3** | Independent, Behavioral | Drunk Driver | Binary | Indicates whether a driver involved in the crash was suspected of drinking (i.e., the "dr_drink" variable) |
| **4** | Independent, Behavioral | Night | Binary | Night is defined as being between 7 PM and 6 AM |
| **5** | Independent, Demographic | High-Fatality States | Binary | High-fatality states are those identified in Kahane's report |
| **6** | Independent, Behavioral | Restraint System | Binary | Indicates if the driver was wearing a seat belt[53] |
| **7** | Independent, Behavioral | Speed Limit | Binary | Indicates if the posted speed limit is over 55 MPH |
| **8** | Independent, Demographic | Male Driver | Binary | Indicates if the driver of a vehicle involved in the crash is a male |
| **9** | Independent, Demographic | Age-gender variables | Binary | A set of eight variables capturing driver age and gender per Wenzel and Kahane |

*Notes: The Kahane report identifies high-fatality states on page 28. The eight age-gender variables are: Female (15-30), Female (31-50), Female (51-70), Female (71-96), Male (15-30), Male (31-50), Male (51-70), and Male (71-96).*

Conducting stepwise multivariate regressions, one variable was added in at a time in descending order of coefficient magnitude from the single-variate regressions. Detailed results from the single-variate regressions are provided in Appendix B.

The results from the full multivariate regression are presented in Table 4 below. Each coefficient represents the effect that the variable has on crash fatalities as a percentage of vehicle occupancy. The statistical significance represents the likelihood that the relation between the dependent and independent variable as observed in the data also exists in the greater population.

The results are presented in decreasing order of coefficient magnitude and are separated by variables with negative coefficients (i.e., variables which decrease the crash fatalities as a percentage of vehicle occupancy) and variables with positive coefficients (i.e., variables which increase the crash fatalities as a percentage of vehicle occupancy). Detailed results from the stepwise multivariate regressions are included in Appendix B.

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[53] We note that seat belt use rates may be inflated in the FARS data, as survivors may report to first responders that they were wearing a seat belt even when they were not. Nonetheless, we find the use of a restraint system to be an important variable when determining the factors effecting fatalities as a percent of occupancy and therefore include it in our regression analysis.

**Table 4. Multivariate regression coefficients and statistical significance**[54]

| Variable | Coefficient | Statistical Significance |
|---|---|---|
| **Negative - Decrease in Fatality Rate per Number of Occupants** | | |
| **Restraint System** | -34.8% | *** |
| **Male (15-30)** | -10.6% | ** |
| **Male (31-50)** | -9.6% | * |
| **Night** | -4.0% | *** |
| **Female (15-30)** | -3.9% | |
| **Female (31-50)** | -3.1% | |
| **Male (51-70)** | -1.4% | |
| **Model Year** | -0.9% | *** |
| **Positive - Increase in Fatality Rate per Number of Occupants** | | |
| **Female (71-96)** | 31.0% | *** |
| **Drunk Driver** | 23.3% | *** |
| **Male (71-96)** | 17.4% | *** |
| **Female (51-70)** | 9.4% | • |
| **Speed Limit >= 55** | 9.1% | *** |
| **Male Driver** | 6.9% | |
| **High Fatality State** | 1.5% | *** |
| **Calendar Year** | 0.2% | *** |

*Notes: • indicates statistical significance at the 90% confidence level; * indicates statistical significance at the 95% confidence level; ** indicates statistical significance at the 99% confidence level; and*** indicates statistical significance at the 99.9% confidence level.*

Like the NHTSA analysis, the regression results show that each additional model year reduces the rate of fatalities per occupant. A coefficient of -0.9 percent on the model year variable indicates that each newer model year reduces the fatalities as a percentage of vehicle occupancy by a statistically significant 0.9 percent.[55] This suggests that the fatality rate per occupants decreases for newer vehicles. On the other hand, holding vehicle model year fixed, the fatality rate per occupant increased over time by 0.2 percent for each calendar year. The independent variables with the largest effects are behavioral and

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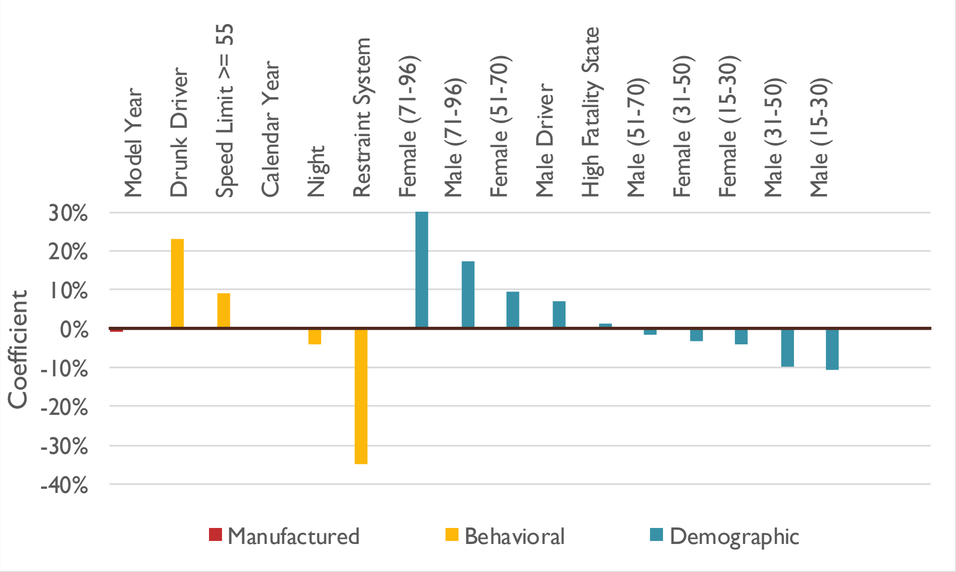
[54] Several of the coefficients from the results of the multivariate regression differ from those included in the Kahane and Wenzel studies. While the analysis was informed by those studies, this analysis relied on a different functional form for the regression, and used a different dependent variable – that is, fatality rate as a percentage of occupants.

[55] The NHTSA analysis includes a similar finding. Its findings show that the percent of occupants killed in MY 2008-2012 vehicles is 31% and the percent killed in MY 2013-2017 vehicles is 26%. If we assume the percent values are attributed to the mid-year in each of the model year ranges – that is, 2010 and 2015 – then the annual reduction in percent killed is: (31% – 26%)/(2010 – 2015) = -1%. See Figure 1 in the NHTSA analysis.

demographic; namely, the use of a restraint system, the presence of a drunk driver, posted speed limit, and gender and age variables. The first three increase the likelihood of a fatality, and the coefficients on the gender and age variables suggest that the presence of older drivers is associated with a higher fatality rate per occupant in fatal crashes. This is aligned with the results found in Wenzel (2018), which states that "[m]any of the control variables NHTSA includes in its logistic regressions are statistically significant and have a much larger estimated effect on fatality risk than vehicle mass," including gender variables and speed limit.

Figure 5 below presents the coefficients from the full multivariate regression in bar chart format for comparison. Again, the largest effects are behavioral and demographic.

**Figure 5. Coefficients from multivariate regression**



## 4.3. Findings

New vehicles employ new technologies, which have made them safer over time. This is evidenced by the positive and statistically significant coefficient on the model year variable in our multivariate regression analysis. However, behavior and demographics—namely, the use of a restraint system, the presence of a drunk driver, posted speed limiting, and gender and age—more strongly influence fatality risk than a vehicle's model year.

# 5. ASSESSMENT OF NHTSA/EPA VEHICLE SALES AND SAFETY ANALYSIS

## 5.1. Errors in the NHTSA/EPA Analysis in the Draft Rule

The NPRM analysis shows that decreases in prices of new vehicles have the potential to increase new vehicle sales, making the vehicle fleet newer, on average. As these newer vehicles are safer, as newer vehicles are manufactured with safety technology designed to reduce injury and death in crashes, increases in the proportion of newer vehicles in the fleet increases vehicle fleet safety.

However, one of the primary concerns with the NPRM analysis of the draft rule is the way compliance costs represent changes in upfront purchase price and do not include changes in fuel spending.[56] Compliance costs should be analyzed using a total cost of ownership approach instead. A total cost of ownership approach includes the net effect of changes in purchase price and fuel spending. It is important to include the net effects of these two changes because it more accurately represents the total incremental cost of a new vehicle.

In addition to the issue with what is and is not included in the analysis of compliance costs, there are errors in the key assumptions used in the analysis of the draft rule. Using the Notice of Proposed Rulemaking and Preliminary Regulatory Impact Analysis ("NPRM/PRIA") assumptions, the draft rule forecasts an increase in vehicle sales for all model years. Figure 6 below illustrates the results using the agencies' problematic approach and erroneous assumptions.

The decrease in fuel economy (and therefore increase in fuel spending) between the existing standards and draft rule do not offset the gross price premium of the more fuel-efficient vehicles when using the agencies' flawed assumptions. [57,58] Using these flawed assumptions implies that consumers that are in the market for a new vehicle will perceive a draft rule-compliant vehicle to be less costly, and therefore be more likely to purchase a new vehicle.

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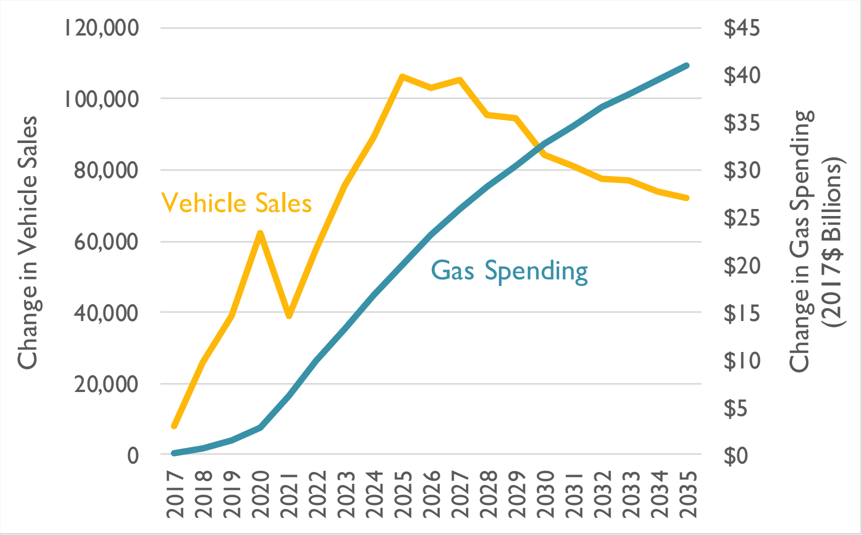
[56] Table 8-1 on page 953 of the PRIA includes neither a consumer valuation of fuel savings variable nor a net price premium variable, indicating consumer valuation of fuel spending is not incorporated when estimating the change in vehicle sales.

[57] Although the rule will not be in effect until 2021, the NPRM does suggest vehicle price changes for MYs 2017 through 2020, before the rule begins to take effect. Therefore, we see an increase in sales for MYs 2017 through 2020.

[58] The drop in the change in vehicle sales in 2021 is because MY 2021 is the first year in which there are significant differences between the existing vehicle standards and the vehicle standards under the draft rule.

Figure 6. Change in gas spending and vehicle sales in the NPRM/PRIA scenario



## 5.2. Proposed Corrections

Synapse developed a total cost of ownership model earlier this year and applied this model in a macroeconomic analysis for the Union of Concerned Scientists (UCS) as well as a second macroeconomic analysis for the Natural Resources Defense Council (NRDC). The UCS analysis explored the macroeconomic effects of federal and state vehicle standards.[59] The NRDC analysis looked at the macroeconomic effects of clean vehicle scenarios for Colorado.[60]

An updated version of this model is used to analyze the effect of changes in the total cost of ownership on vehicle sales under the draft rule.[61] The effect of the draft rule of the existing standards on vehicle sales is explored by netting out the various effects of the draft rule on the price premium. This net price premium, which is also referred to as the compliance cost, represents the perceived total incremental cost of a newly-purchased draft rule-compliant vehicle, accounting for: (1) the purchase price of the new vehicle, (2) vehicle financing costs, and (3) consumer valuation of fuel spending over the life of the vehicle.[62]

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[59] Allison, A., J. Hall, and F. Ackerman. 2018. *Cleaner Cars and Job Creation: Macroeconomic Impacts of Federal and State Vehicle Standards.* Synapse Energy Economics for UCS, NRDC, ACEEE. http://www.synapse-energy.com/sites/default/files/Cleaner-Cars-and%20Job-Creation-17-072.pdf.

[60] Allison, A. and J. Hall. 2018. *Macroeconomic Analysis of Clean Vehicle Scenarios for Colorado*. Synapse Energy Economics for Environmental Entrepreneurs. https://www.e2.org/wp-content/uploads/2018/06/CO-Clean-Vehicle-Macroeconomic-Impacts-Final-Report-20180612-FINAL.pdf.

[61] Table 7-43 on page 593 of the PRIA shows that the draft rule will increase vehicle sales by 1 million for MYs 2017–2029. The NPRM/PRIA scenario similarly estimates that the rule will increase vehicle sales by 0.9 million for MYs 2017–2029, suggesting that the model is mostly aligned with the modeling used for the NPRM analyses and results.

[62] Note that the net price premium is the *perceived* total incremental cost of a newly-purchased draft rule-compliant vehicle, as it includes the assumed consumer valuation of fuel spending.

Table 5 below provides an overview of the assumptions used and the problem with some of the assumptions. In particular, (a) the compliance cost estimates are larger than those provided in the 2016 Draft TAR as well as estimates by other experts, (b) the rebound effect is inconsistent with the literature, (c) the fuel prices are outdated, (d) the baseline vehicle sales projection does not align with other established sales projections, and (e) the sales model in the NPRM does not incorporate consumer valuation of fuel savings.

Of those five issues, the analysis indicates that the assumptions that drive the most significant changes in vehicle sales include compliance costs and rebound effect. As a result, the agencies should update these inputs to achieve more credible results.

**Table 5. Issues with the NPRM/PRIA assumptions and alternatives**

| Key Input | Assumption | Source | Problems with Assumption | Proposed Corrections |
|---|---|---|---|---|
| **Gross price premium a/k/a compliance costs** | NPRM estimates of average light-duty vehicle (LDV) price changes, broken into average LDV price changes for trucks and cars using PRIA technology costs | NPRM, p. 43,265;<br>PRIA, p. 593-599 | The compliance costs included in the NPRM are notably larger than those included in the agencies' 2016 Draft Technical Assessment Report (TAR)[63] | More reasonable compliance costs associated with the draft rule as developed by UCS, the International Council on Clean Transportation (ICCT), and the California Air Resources Board (CARB)[64] |
| **Rebound effect** | 20% | NPRM, p. 43,107 | 20% is outside the range of most estimates of the rebound effect provided in leading reports | A 10% rebound effect, in line with the values estimated in leading reports[65] |
| **Fuel prices** | AEO 2017 Reference Case | NPRM, p. 43,069 | These are outdated fuel price projections | AEO 2018 Reference Case fuel prices |
| **Fuel economy standards** | The NPRM holds the 2020 standards flat. The PRIA's LDV achieved standards are broken out into truck- and car-specific achieved standards using the proposed NPRM standards. | NPRM, p. 42,989;<br>PRIA, p. 537-540 | n/a | n/a |
| **Price elasticity of demand** | The NPRM states that alternative estimates of the model's coefficient range from -0.2 to -0.3. The | NPRM, p. 43,075 | n/a | n/a |

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[63] EPA and NHTSA. July 2016. *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*. Table 13.9, p. 13-73.

[64] See Figure 11 through Figure 14 for a comparison of compliance cost estimates.

[65] See, for example: Gillingham, K., Jenn, A., & Azevedo, I. M. (2015). *Heterogeneity in the response to gasoline prices: Evidence from Pennsylvania and implications for the rebound effect*. Energy Economics, 52, S41-S52. See also: Wenzel, T. P., & Fujita, K. S. (2018). *Elasticity of Vehicle Miles of Travel to Changes in the Price of Gasoline and the Cost of Driving in Texas*. LBNL.

| Key Input | Assumption | Source | Problems with Assumption | Proposed Corrections |
|---|---|---|---|---|
| | midpoint of this range (-0.25) is used as the price elasticity. The actions customers may take who decide not to purchase a new vehicle are not accounted for. | | | |
| **Consumer valuation of fuel economy** | The NPRM references a study which finds that new vehicle buyers value at least three-quarters of future fuel savings, which is more than the 32% previously assumed by the agencies. However, it does not state the exact consumer valuation period included in its analyses, so 30 years is used. | NPRM, p. 43,074 | The vehicle sales model used in the report should incorporate some degree of consumer valuation of fuel economy | n/a |
| **Vehicle sales projections** | The NPRM includes LDV sales projections. The LDV sales projection is broken out into car and truck sales. | NPRM, p. 43,076 | The vehicle sales projection provided in the NPRM does not align with projections in IHS/Polk, AEO 2017, or even actual historical sales | n/a |
| **Financing parameters** | The PRIA notes that the percentage of consumers who finance a new vehicle purchase is 85%. The PRIA also notes an average loan rate of 4.25%. | PRIA, p. 958-959 | n/a | n/a |
| **On-road fuel economy gap** | Assumes on-road vehicles achieve fuel economy 20% below rate values. | | n/a | n/a |
| **Baseline car and truck prices** | The NPRM includes baseline LDV prices. | NPRM, p. 43,291 | n/a | n/a |

Table 5 proposes several corrections to assumptions included in the NPRM. This section describes a Synapse scenario which adjusts several of the inputs to be more appropriate. Table 6 lists the modifications to the inputs for the Synapse scenario and its sensitivity. The following adjustments were implemented:

1. **Rebound effect.** Synapse changed the rebound effect from 20 percent to 10 percent. This is aligned with the agencies' previous analysis in the Draft Technical Assessment Report (TAR), as well as existing literature on the rebound effect. Leading reports on the topic suggest that the actual rebound effect is closer to 10 percent rather than 20 percent.[66]

2. **Compliance cost estimates**. The compliance costs included in the NPRM are notably larger than those included in the agencies' 2016 Draft TAR. Therefore, three more realistic compliance cost estimates (UCS, ICCT, and CARB) were applied. In the UCS sensitivity, compliance costs were developed by UCS in a modified version of the Volpe

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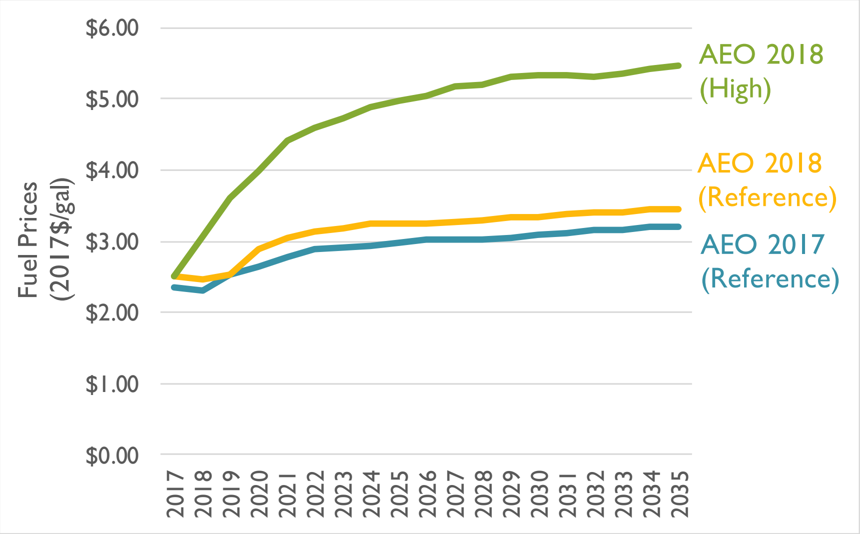
[66] See, for example: Gillingham, K., Jenn, A., & Azevedo, I. M. (2015). *Heterogeneity in the response to gasoline prices: Evidence from Pennsylvania and implications for the rebound effect*. Energy Economics, 52, S41-S52. See also: Wenzel, T. P., & Fujita, K. S. (2018). *Elasticity of Vehicle Miles of Travel to Changes in the Price of Gasoline and the Cost of Driving in Texas*. LBNL.

model. The model was modified to better align with the EPA OMEGA results provided in the 2016 TAR. In the ICCT sensitivity, the compliance costs associated with the standards were developed by the International Council on Clean Transportation (ICCT). In the CARB sensitivity, compliance costs were developed by the California Air Resources Board (CARB) using the CAFE Model developed for the 2016 Draft TAR. The model was modified such that the vehicle standards for the draft rule scenario are flatlined beginning with model year 2021 to align with the current proposal.

3. **Fuel price projections.** While it is not necessarily an error in the NPRM analysis, the most recently available fuel price projections should be used (from AEO 2018 rather than those from AEO 2017) as they reflect more recent events and outlooks on future prices.[67] We also examine a high fuel price sensitivity.[68] The fuel price projections used in each of our scenarios and the sensitivity are included in Figure 7 below.

Figure 7. Comparison of Fuel Price Projections



Several scenarios were modeled to test the effect of changes in key inputs on vehicle sales. After showing the change in vehicle sales due to the draft rule, the total fleet-wide change in fuel spending is shown for the draft rule.

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[67] AEO 2017 (NPRM, p. 43,069)

[68] The 2018 AEO low fuel price projections are not analyzed as they are improbable.

Table 6. Synapse scenarios and sensitivity

| Inputs | NPRM | Synapse Scenario 1 (UCS) | Synapse Scenario 2 (ICCT) | Synapse Scenario 3 (CARB) | Synapse Scenario 1 (UCS) – High Fuel Price Sensitivity |
|---|---|---|---|---|---|
| **Rebound effect** | 20% | 10% | 10% | 10% | 10% |
| **Fuel prices** | AEO 2017 Reference Case | AEO 2018 Reference Case | AEO 2018 Reference Case | AEO 2018 Reference Case | AEO 2018 High Oil Price Case |
| **Gross price premium a/k/a compliance costs** | NPRM estimates of average light-duty vehicle (LDV) price changes, broken into average LDV price changes for trucks and cars using PRIA technology costs. | UCS | ICCT | CARB | UCS |

Figure 8 below illustrates the change in fuel spending for the NPRM scenario, compared to the three Synapse scenarios and the Synapse sensitivity.

Figure 8. Estimates of increase in fleet-wide fuel spending with draft rule

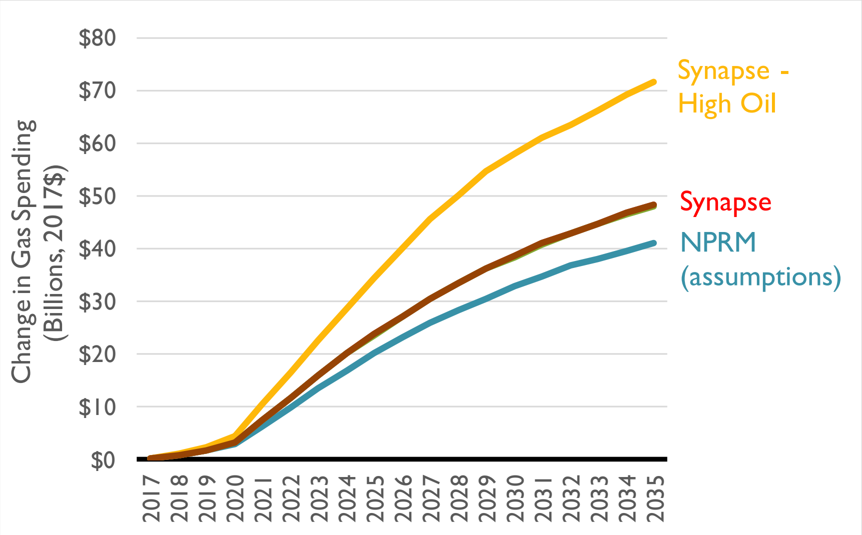
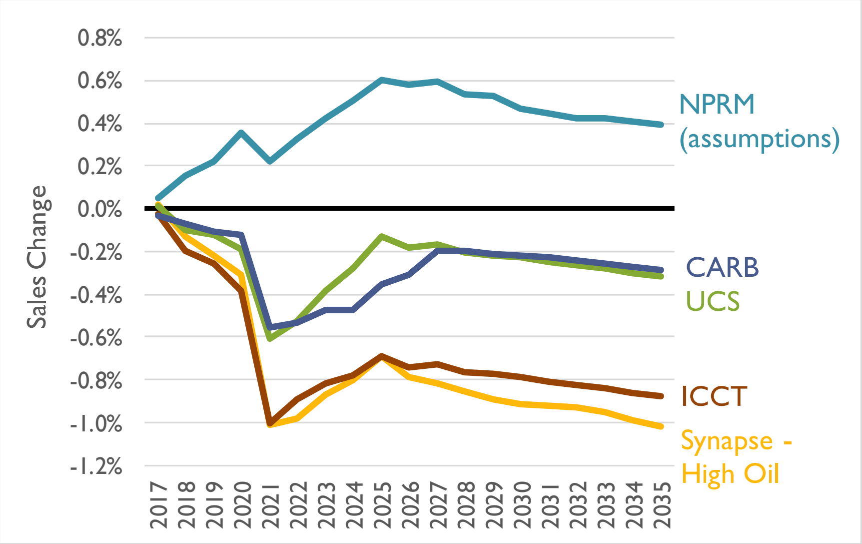


Figure 9 below illustrates the change in vehicle sales for the NPRM, versus the three Synapse scenarios and the Synapse sensitivity.

**Figure 9. Estimates of changes in vehicle sales from the draft rule**



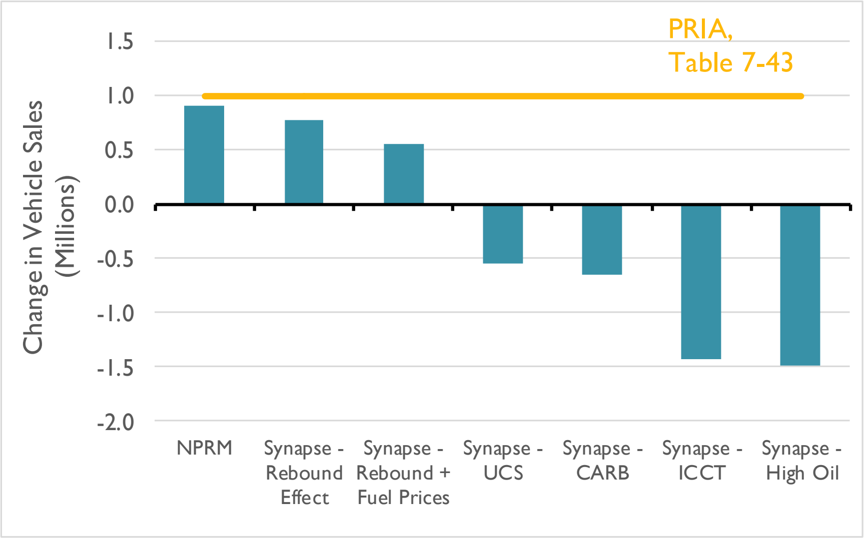
To make the influence of each input change on the results more apparent, Figure 10 below shows them one at a time. The first update is to the rebound effect. Next, fuel prices are updated to reflect the most recent reference case. Then three different compliance costs are modeled. Lastly, a sensitivity is conducted for high fuel prices based on the UCS compliance cost.

Updating the rebound effect decreases the effect estimated in the NPRM by approximately 230,000 sales. Adding in the fuel price change shows a reduction in sales by an additional 212,000 sales. Applying the compliance cost estimates in tandem with the other updates decreases the effect by an additional 1.1 million sales in the UCS scenario, an additional 1.2 million sales in the CARB scenario, and an additional 2 million sales in the ICCT scenario. High fuel prices decrease the effect estimated in the UCS scenario by approximately 935,000 sales.

The ICCT compliance costs estimates for vehicles compliant with the existing standards are the lowest compliance cost estimates. Therefore, these costs have the largest effect on the estimated change in vehicle sales. This is because lower costs make more efficient vehicle purchases more affordable. Figures depicting the gross and net price premiums for each scenario are included in Appendix C: Total Cost of Ownership Modeling Detailed Results

The high oil price sensitivity shows a substantial decrease in the estimated vehicle sales change. The update from AEO 2017 to AEO 2018 baseline data does not have much of a cumulative impact on vehicle sales.

**Figure 10. Cumulative change in MY 2017–2029 vehicle sales (millions) by scenario and sensitivity**



## 5.3. Findings

Using corrected approach and assumptions, the draft rule increases fleet-wide fuel spending and decreases vehicle sales in each scenario. Our analysis finds that the decreases in fuel economy (and therefore increased fuel spending) between the existing standards and draft rule outweigh the decreases in compliance costs, and therefore increase the total cost of ownership. Table 7 shows that the increase in the total cost of ownership decreases vehicle sales. Detailed figures on fuel spending, gross price premiums, and net price premiums are included in Appendix C: Total Cost of Ownership Modeling Detailed Results

**Table 7. Cumulative change in aggregated gross price premiums, aggregated fuel spending, aggregated perceived net price premium and vehicle sales (2017-2035) by scenario and sensitivity**

| Cumulative Change (2017-2035) | NPRM | Synapse Scenario 1 (UCS) | Synapse Scenario 2 (ICCT) | Synapse Scenario 3 (CARB) | Synapse Scenario 1 (UCS) – High Fuel Price Sensitivity |
|---|---|---|---|---|---|
| **Aggregated Gross Price Premiums,[69] (Billions, 2017$)** | -$520 | -$390 | -$250 | -$380 | -$450 |
| **Aggregated Fuel Spending (Billions, 2017$)** | $400 | $470 | $470 | $470 | $700 |
| **Aggregated Perceived Net Price Premium,[70] (Billions, 2017$)** | -$190 | $130 | $340 | $140 | $370 |
| **Vehicle Sales** | 1,368,000 | -848,000 | -2,338,000 | -918,000 | -2,528,000 |

The compliance cost and rebound effect assumptions drive the most significant changes in vehicle sales. The compliance cost estimates are larger than those provided in the 2016 Draft TAR, as well as estimates by other experts, and the rebound effect is inconsistent with the literature. These inputs should be corrected.

The NPRM suggests that the draft rule will avoid fatalities. However, this claim is based on an analysis that relies on a flawed approach and several unreasonable inputs. Each of the Synapse scenarios and the sensitivity find the draft rule reduces vehicle sales. Reduced vehicle sales will lead to an older vehicle fleet. The results from Section 4 find that the number of fatalities as a percent of occupancy is lower for newer model years as compared to older model years. Therefore, the older vehicle fleet under the draft rule would likely increase fatalities rather than avoid them.

# 6. OPPORTUNITIES FOR ADDITIONAL RESEARCH

The research presented in this report was based on publicly available data. The research did not include proprietary datasets such as R. L. Polk's National Vehicle Population Profile, which would have allowed for a better exploration of induced-exposure in the regression analyses. Also, the research on the relationship between vehicle safety and model year was limited in several ways. For example, the effects of multiple, new technologies on vehicle safety are enmeshed in the data and are therefore difficult to disaggregate. Were these technologies disaggregated in the data, Synapse could have

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[69] Aggregated gross price premiums multiply gross price premiums by vehicle, by projected vehicle sales.

[70] This represents the summation of the perceived total cost of ownership (that is, the net price premium), multiplied by projected vehicle sales. The perceived total cost of ownership incorporates assumptions documented in Table 5 such as financing parameters. Therefore, it does not equal the sum of aggregated gross price premiums and fuel spending.

accounted for their effects individually. Finally, the analysis is dependent on self-reported data for restraint system use.

Additional research is needed on the effects of federal CAFE standards. Research topics could include:

- Additional investigation of factors affecting vehicle safety, including combining the FARS dataset with the R. L. Polk' NVPP and NHTSA's induced-exposure datasets;
- Further exploration of the purchase decisions that are made when a consumer foregoes purchasing a new vehicle due to the price premium; and,
- A more detailed analysis of the effect of specific crash avoidance technologies on fatality coefficients.

# 7. CONCLUSIONS

There are many ways for automakers to achieve fuel economy standards that maintain or even improve vehicle safety. Fuel economy and vehicle safety have improved for vehicles of all weights and sizes due to safety-related technological advances such as air bags, improvements to structural integrity and braking systems, electronic stability control, and advanced driver assistance systems. Mass reduction is another option and can be done using new higher-quality lightweight materials that offer greater protection for vehicle occupants and improve vehicle safety. Automakers can and do combine new safety-related technologies and mass reduction techniques for optimal fuel economy and vehicle safety.

Each year, new vehicle models employ the best new safety technologies and mass reduction techniques available. The adoption of new technologies and practices has made new vehicles safer over time. However, the use of a restraint system, the presence of a drunk driver, posted speed limiting, and gender and age of the driver are more indicative of fatality risk than the newness of a vehicle. Concerns about vehicle safety should focus on accelerating the deployment of safety technology and changing consumer behavior rather than the rate of vehicle turnover.

The total cost of ownership of new vehicles can affect the rate of vehicle turnover. However, more efficient cars and trucks have a lower total cost of ownership when fuel savings are properly accounted for and erroneous cost and rebound effect assumptions are corrected.

# APPENDIX A: REFERENCES

Ahmed, Sanjana and David L. Greene. 2005. "Effect of Fuel Economy on Automobile Safety: A Reexamination." *Transportation Research Record* 1941.1: 1-7.

Allison, A. and J. Hall. 2018. *Macroeconomic Analysis of Clean Vehicle Scenarios for Colorado*. Synapse Energy Economics for Environmental Entrepreneurs. https://www.e2.org/wp-content/uploads/2018/06/CO-Clean-Vehicle-Macroeconomic-Impacts-Final-Report-20180612-FINAL.pdf.

Allison, A., J. Hall, and F. Ackerman. 2018. *Cleaner Cars and Job Creation: Macroeconomic Impacts of Federal and State Vehicle Standards.* Synapse Energy Economics for UCS, NRDC, ACEEE. http://www.synapse-energy.com/sites/default/files/Cleaner-Cars-and%20Job-Creation-17-072.pdf.

Beene, Ryan and John Lippert. 2018. "Safety Gains from Heavier Cars may be Cited to Cut MPG Rules." Bloomberg.

Bento, et al. 2017. *The Effect of Fuel Economy Standards on Vehicle Weight Dispersion and Accident Fatalities*. National Bureau of Economic Research. Working Paper 23340.

Kahane, C. J. 2012. "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs – Final Report." (Report No. DOT HS 811 665). Washington, DC: National Highway Traffic Safety Administration.

Kahane, C. J. 2015. "Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes." (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration.

Farmer, Charles M. and Adrian K. Lund. 2015."The Effects of Vehicle Redesign on the Risk of Driver Death." *Traffic Injury Prevention* 16: 684-690.

National Highway Traffic Safety Administration. 2009. "Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks: Final Regulatory Impact Analysis."

National Highway Traffic Safety Administration. 2018. "Passenger Vehicle Occupant Injury Severity by Vehicle Age and Model Year in Fatal Crashes. Traffic Safety Facts: Research Note. DOT HS 812 528.

National Research Council. 2015. "Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light Duty Vehicles." National Academy of Sciences.

Puckett, S.M. and J.C. Kindelberger. 2016. “Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs – Preliminary Report. (Docket No. NHTSA-2016-0068). Washington, D.C: National Highway Traffic Safety Administration.

Ross, Marc and Tom Wenzel. 2002. “An Analysis of Traffic Deaths by Vehicle Type and Model.” American Council for an Energy-Efficient Economy.

United States Environmental Protection Agency and National Highway Traffic Safety Administration. 2012. “2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards.” Federal Register 77.199.

United States Environmental Protection Agency. 2016. “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-16-901.

United States Environmental Protection Agency. 2017. “Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation.” EPA-420-R-17-001.

US Environmental Protection Agency. 2018. “Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report: 1975 Through 2017.” EPA-420-R-18-001.

Van Auken, R.M. and Zellner, J.W. 2005. “An Assessment of the Effects of Vehicle Weight and Size on Fatality Risk in 1985 to 1998 Model Year Passenger Cars and 1985 to 1997 Model Year Light Trucks and Vans,” SAE Technical Paper 2005-01-1354, SAE 2005 Transactions Journal of Passenger Cars: Mechanical Systems-V114-6.

Van Auken, R.M. and Zellner, J.W. 2013. "An Assessment of the Effects of Passenger Vehicle Weight and Size on Accident and Fatality Risk Based on Data for 1991 through 2007 Model Year Vehicles," SAE Int. J. Trans. Safety 1(1):166-191

Wenzel, Tom. 2016. “Assessment of NHTSA’s Report ‘Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs.’” Lawrence Berkeley National Laboratory.

Wenzel, Tom. 2018. “Assessment of NHTSA’s Report ‘Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2004-2011 Passenger Cars and LTVs’ (LBNL Phase 1).” Lawrence Berkeley National Laboratory.

# APPENDIX B: REGRESSION ANALYSIS DETAILED RESULTS

### *Correlation matrix*

Table 8 shows the correlation between each of the variables included in the multivariate regression analysis. A correlation matrix helps identify whether any two variables are strongly correlated with one another. The value in each cell (between -1 and 1) describes the correlation between the two variables; a large positive number means there is a strong positive correlation, and a large negative number means there is a strong negative correlation. The cells that are shaded red indicate stronger positive correlations, whereas the cells that are shaded green indicate stronger negative correlations.

Of the variables included in the analysis, the age/gender variables generally have the strongest correlations with each other. Other pairs with relatively strong correlations include: Model Year and Calendar Year, and Night and Drunk Driver. However, none of the variables exhibit correlations that are strong enough to suggest they should be excluded from the multivariate regression.

**Table 8. Correlation matrix**

| Variable | Model Year | Night | Speed Limit >= 55 | High Fatality State | Restraint System | Drunk Driver | Calendar Year | Male Driver | Male (15-30) | Male (31-50) | Male (51-70) | Male (71-96) | Female (15-30) | Female (31-50) | Female (51-70) | Female (71-96) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Model Year** | NA | -0.01 | 0.04 | 0.01 | -0.04 | -0.05 | 0.57 | -0.05 | -0.06 | -0.01 | 0.02 | -0.02 | 0.02 | 0.04 | 0.05 | -0.03 |
| **Night** | -0.01 | NA | -0.03 | 0.02 | -0.09 | 0.30 | 0.01 | 0.12 | 0.18 | 0.07 | -0.04 | -0.13 | 0.03 | -0.04 | -0.09 | -0.14 |
| **Speed Limit >= 55** | 0.04 | -0.03 | NA | 0.01 | 0.01 | -0.02 | 0.01 | 0.00 | -0.01 | 0.02 | 0.03 | -0.03 | 0.02 | 0.02 | 0.00 | -0.06 |
| **High Fatality State** | 0.01 | 0.02 | 0.01 | NA | -0.04 | -0.01 | 0.01 | -0.04 | -0.01 | 0.00 | -0.03 | -0.02 | 0.02 | 0.03 | 0.01 | 0.00 |
| **Restraint System** | -0.04 | -0.09 | 0.01 | -0.04 | NA | -0.24 | -0.25 | -0.08 | -0.08 | -0.04 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 |
| **Drunk Driver** | -0.05 | 0.30 | -0.02 | -0.01 | -0.24 | NA | 0.03 | 0.14 | 0.16 | 0.09 | -0.03 | -0.09 | -0.04 | -0.04 | -0.08 | -0.08 |
| **Calendar Year** | 0.57 | 0.01 | 0.01 | 0.01 | -0.25 | 0.03 | NA | 0.02 | -0.01 | 0.02 | 0.04 | -0.02 | -0.02 | -0.01 | 0.01 | -0.02 |
| **Male Driver** | -0.05 | 0.12 | 0.00 | -0.04 | -0.08 | 0.14 | 0.02 | NA | 0.47 | 0.37 | 0.30 | 0.23 | -0.51 | -0.43 | -0.37 | -0.28 |
| **Male (15-30)** | -0.06 | 0.18 | -0.01 | -0.01 | -0.08 | 0.16 | -0.01 | 0.47 | NA | -0.25 | -0.20 | -0.16 | -0.24 | -0.20 | -0.18 | -0.13 |
| **Male (31-50)** | -0.01 | 0.07 | 0.02 | 0.00 | -0.04 | 0.09 | 0.02 | 0.37 | -0.25 | NA | -0.16 | -0.12 | -0.19 | -0.16 | -0.14 | -0.10 |
| **Male (51-70)** | 0.02 | -0.04 | 0.03 | -0.03 | 0.01 | -0.03 | 0.04 | 0.30 | -0.20 | -0.16 | NA | -0.10 | -0.15 | -0.13 | -0.11 | -0.09 |
| **Male (71-96)** | -0.02 | -0.13 | -0.03 | -0.02 | 0.02 | -0.09 | -0.02 | 0.23 | -0.16 | -0.12 | -0.10 | NA | -0.12 | -0.10 | -0.09 | -0.07 |
| **Female (15-30)** | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | -0.04 | -0.02 | -0.51 | -0.24 | -0.19 | -0.15 | -0.12 | NA | -0.15 | -0.13 | -0.10 |
| **Female (31-50)** | 0.04 | -0.04 | 0.02 | 0.03 | 0.03 | -0.04 | -0.01 | -0.43 | -0.20 | -0.16 | -0.13 | -0.10 | -0.15 | NA | -0.11 | -0.09 |
| **Female (51-70)** | 0.05 | -0.09 | 0.00 | 0.01 | 0.04 | -0.08 | 0.01 | -0.37 | -0.18 | -0.14 | -0.11 | -0.09 | -0.13 | -0.11 | NA | -0.07 |
| **Female (71-96)** | -0.03 | -0.14 | -0.06 | 0.00 | 0.04 | -0.08 | -0.02 | -0.28 | -0.13 | -0.10 | -0.09 | -0.07 | -0.10 | -0.09 | -0.07 | NA |

### *Single-variate regression results*

Table 9 below presents the results from the single-variate regression analyses, in which each variable is ran separate from the others. The results are presented in decreasing order of the absolute magnitude of the coefficient.

### Table 9. Single-variate regression results

| Variable | Coefficient |
|---|---|
| **Restraint System** | -38.00% |
| **Drunk Driver** | 24.83% |
| **Female (71-96)** | 22.42% |
| **Male (71-96)** | 18.92% |
| **Female (15-30)** | -9.54% |
| **Female (31-50)** | -8.59% |
| **Speed Limit >= 55** | 7.18% |
| **Male Driver** | 3.88% |
| **High Fatality State** | 2.66% |
| **Male (51-70)** | 2.40% |
| **Male (15-30)** | -1.93% |
| **Female (51-70)** | 1.11% |
| **Model Year** | -1.02% |
| **Male (31-50)** | -0.91% |
| **Calendar Year** | -0.82% |
| **Night** | 0.55% |

### *Stepwise multivariate regression results*

Table 10 below presents the stepwise multivariate regression results. One variable—or group of related variables— was added at a time, to better identify the effect that each variable has on the regression results. The single-variate regression results inform the order in which the variables were added. The final regression—Regression VII—is the full multivariate regression, which were discussed in greater detail in Section 4 of this report.

### Table 10. Stepwise multivariate regression results

| Variable | Regression I | | Regression I | | Regression II | | Regression III | | Regression IV | | Regression V | | Regression VII | | Regression VII | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. | Coef. | Stat. Sig. |
| Restraint System | -38.0% | *** | -33.4% | *** | -34.0% | *** | -34.2% | *** | -34.2% | *** | -35.3% | *** | -34.7% | *** | -34.8% | *** |
| Drunk Driver | | | 18.0% | *** | 22.6% | *** | 22.8% | *** | 22.9% | *** | 22.0% | *** | 22.0% | *** | 23.3% | *** |
| Male (15-30) | | | | | -11.3% | ** | -12.6% | ** | -12.5% | ** | -10.8% | ** | -10.9% | ** | -10.6% | ** |
| Male (31-50) | | | | | -10.3% | * | -11.8% | ** | -11.7% | ** | -9.5% | * | -9.6% | * | -9.6% | * |
| Male (51-70) | | | | | -1.7% | | -3.5% | | -3.4% | | -0.8% | | -1.0% | | -1.4% | |
| Male (71-96) | | | | | 17.4% | *** | 16.4% | *** | 16.5% | *** | 18.4% | *** | 18.3% | *** | 17.4% | *** |
| Female (15-30) | | | | | -3.6% | | -5.8% | | -5.6% | | -3.4% | | -3.6% | | -3.9% | |
| Female (31-50) | | | | | -2.9% | | -5.1% | | -5.0% | | -2.2% | | -2.5% | | -3.1% | |
| Female (51-70) | | | | | 9.5% | . | 7.4% | | 7.6% | | 10.5% | * | 10.2% | * | 9.4% | . |
| Female (71-96) | | | | | 32.2% | *** | 31.1% | *** | 31.3% | *** | 32.6% | *** | 32.3% | *** | 31.0% | *** |
| Male Driver | | | | | 8.1% | | 7.5% | | 7.6% | | 7.3% | | 7.1% | | 6.9% | |
| Speed Limit >= 55 | | | | | | | 8.9% | *** | 8.9% | *** | 9.3% | *** | 9.3% | *** | 9.1% | *** |
| High Fatality State | | | | | | | | | 1.2% | *** | 1.4% | *** | 1.4% | *** | 1.5% | *** |
| Model Year | | | | | | | | | | | -0.8% | *** | -0.9% | *** | -0.9% | *** |
| Calendar Year | | | | | | | | | | | | | 0.2% | *** | 0.2% | *** |
| Night | | | | | | | | | | | | | | | -4.0% | *** |
| Adjusted $R^2$ | 7.9% | | 9.9% | | 15.4% | | 16.4% | | 16.4% | | 18.2% | | 18.2% | | 18.3% | |

# APPENDIX C: TOTAL COST OF OWNERSHIP MODELING DETAILED RESULTS

### *Gross price premiums*

Figure 11 shows a negative gross price premium from the draft rule, by vehicle type, as estimated in the NPRM. The difference between vehicle prices between the two standards is expected to increase until 2026 and then generally plateau.

Figure 11. Gross price premium from draft rule – NPRM/PRIA (2016$/vehicle)

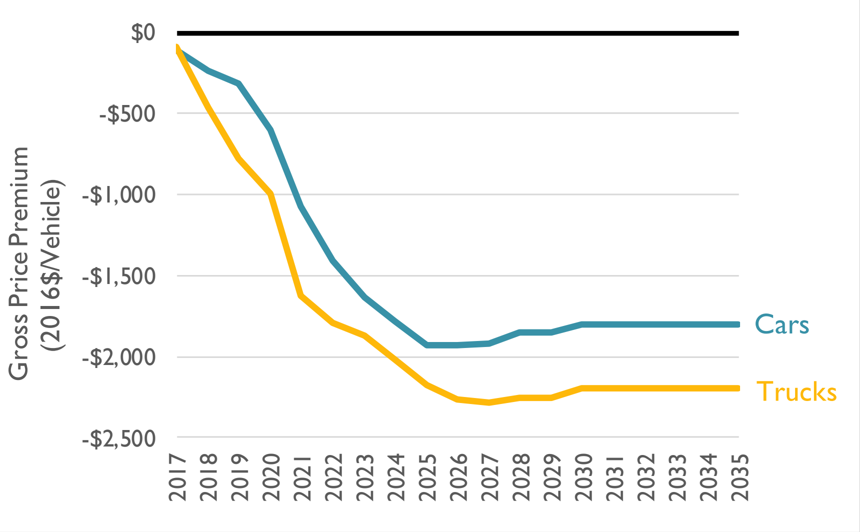


Figure 12, Figure 13, and Figure 14 present the gross price premium from the draft rule when using compliance cost estimates from UCS, ICCT, and CARB, respectively. The gross price premiums are less negative than those in the NPRM (in Figure 11). Each series generally plateaus around MY 2025.

**Figure 12. Gross price premium from draft rule - UCS (2016$/vehicle)**

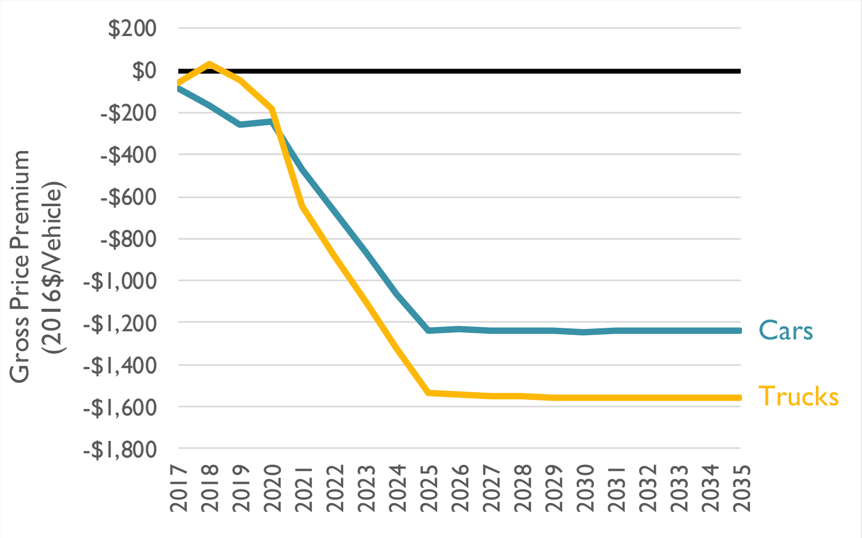


**Figure 13. Gross price premium from draft rule - ICCT (2016$/vehicle)**

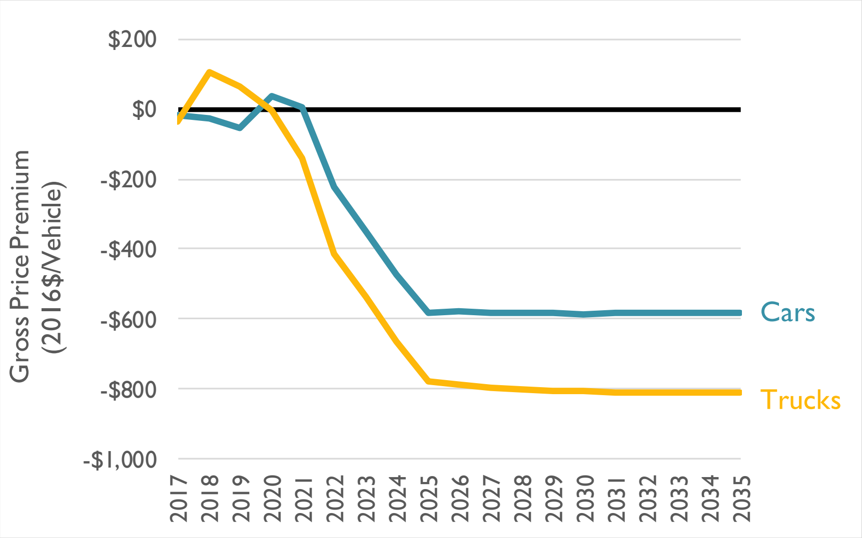
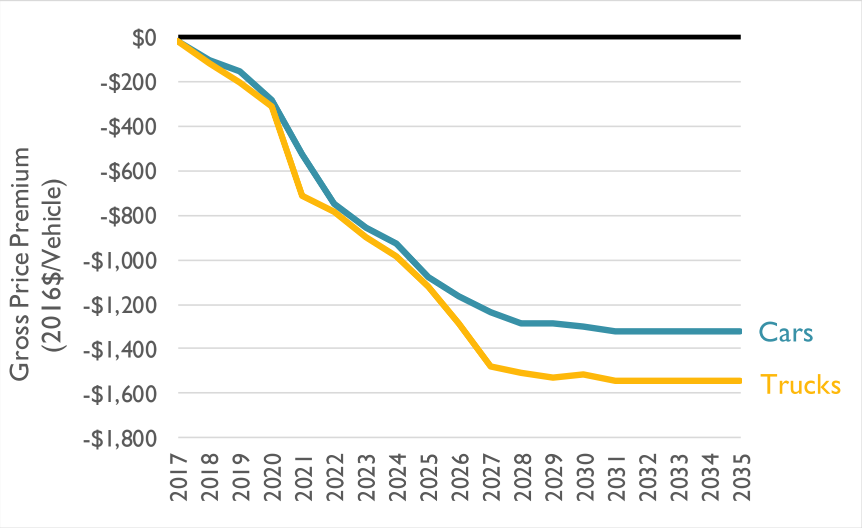


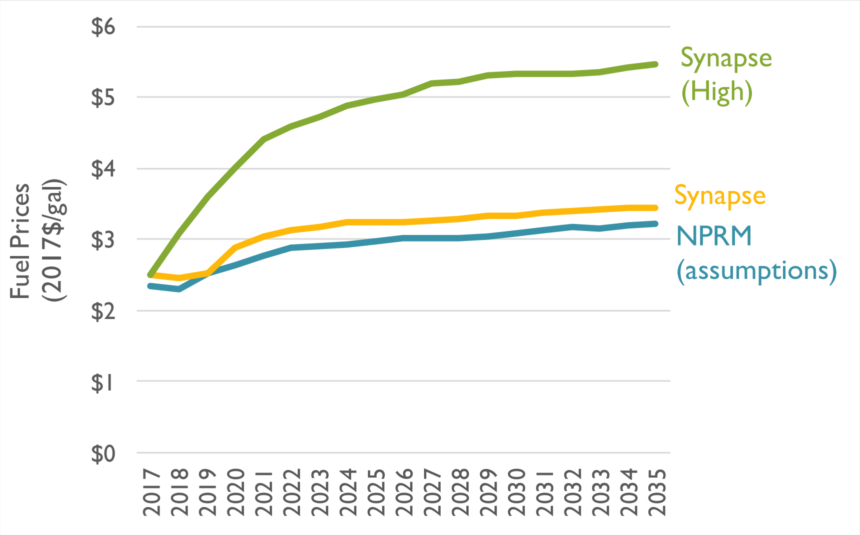
Figure 14. Gross price premium from draft rule - CARB (2016$/vehicle)



### *Fuel spending*

Figure 15 presents the AEO 2017 fuel prices included in the NPRM scenario, as well as the AEO 2018 fuel prices used in the Synapse scenario and its sensitivity (AEO 2018 – Reference and High).

Figure 15. Fuel prices in the NPRM/PRIA and Synapse scenarios



### *Net price premiums (compliance costs)*

These gross price premiums, as well as the additional inputs and assumptions as outlined in Table 6, were included in the Total Cost-of-Ownership Model to estimate the net price premium of draft rule-compliant vehicles compared to existing standards-compliant vehicles. The net price premiums for cars are shown in Figure 16 and the net price premiums for trucks are shown in Figure 17.

In general, the results from the Synapse scenarios show positive net price premiums, indicating that the draft rule will make the perceived incremental cost greater than the existing standards.

Figure 16. Net price premiums from draft rule - cars (2017$)

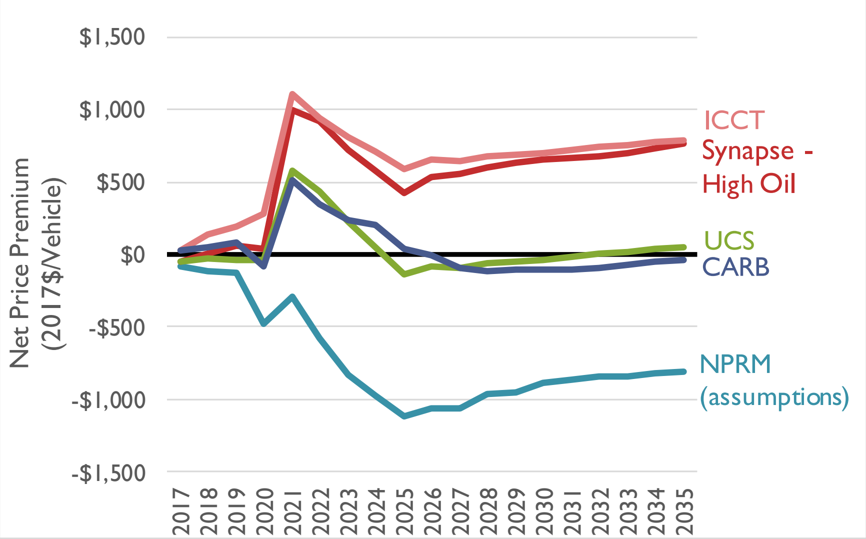
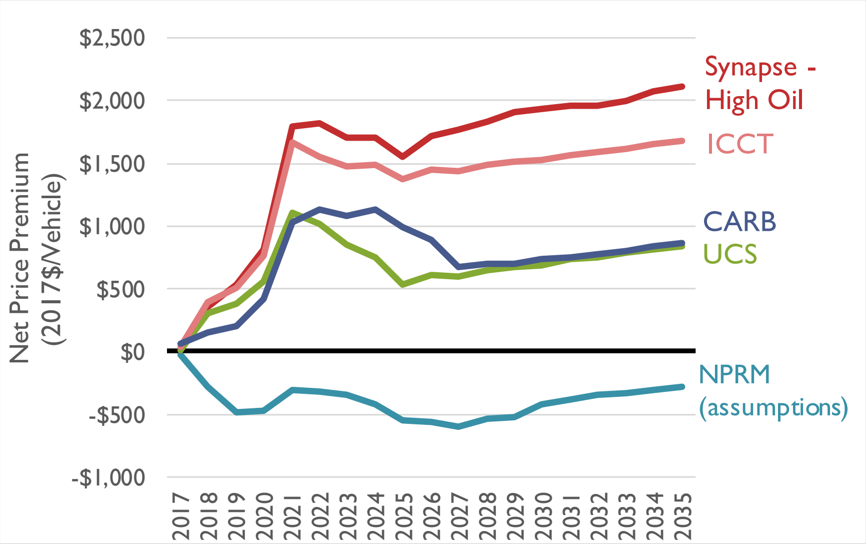


Figure 17. Net price premium from draft rule - trucks (2017$)



### *Change in vehicle sales*

The net price premium, baseline car and truck prices, and the price elasticity are the three primary inputs into the calculation of change in vehicle sales.

Figure 18 and Figure 19 below show the change in vehicle sales as percentages and in terms of actual sales. In general, the results from the Synapse scenarios show a negative change in sales from the draft rule, particularly for trucks.

**Figure 18. Change in car sales – draft rule versus existing standards**

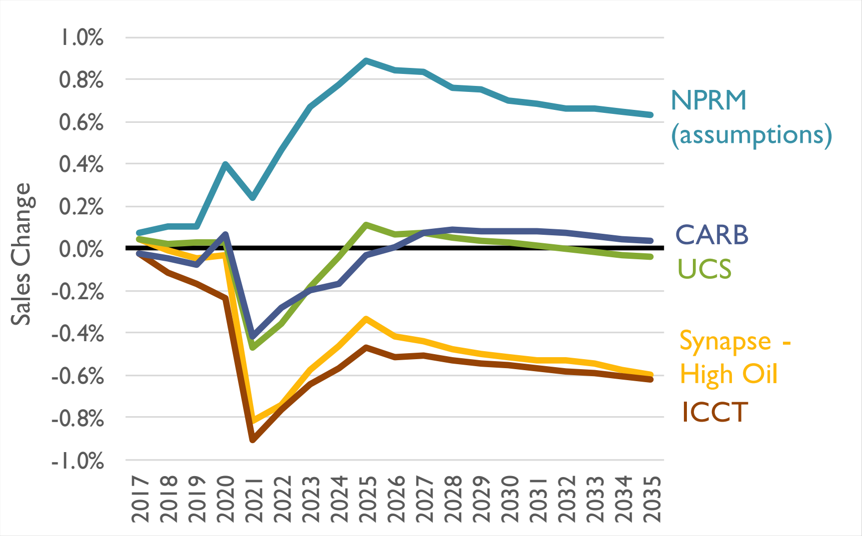
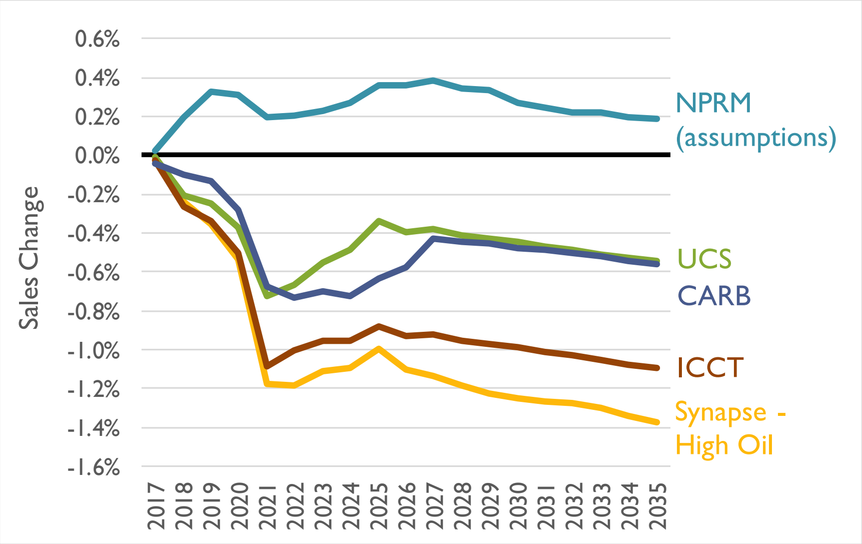


**Figure 19. Change in truck sales – draft rule versus existing standards**



### *Fleet-wide fuel spending*

The existing standard and 2020 draft rule vehicle sales are then used to calculate fleet-wide fuel changes in fuel spending.

The model finds consumer fuel spending increases under the draft rule relative to the existing standards, as one would expect. A reduction in fuel economy standards makes vehicles less fuel-efficient and therefore increases fuel spending. As the gap in standards between the draft rule and the existing standards increase year-over-year, and as vehicle sales increase year-over-year, the fuel spending differences also increase.

Figure 20 and Figure 21 below show changes in fuel spending in the NPRM scenario as well as the Synapse scenario and its sensitivity. Each scenario shows a large increase in fuel spending from the draft rule. The Synapse High Oil sensitivity sees the greatest increase in fuel spending.

**Figure 20. Change in fuel spending from draft rule – car fleet (billions, 2017$)**

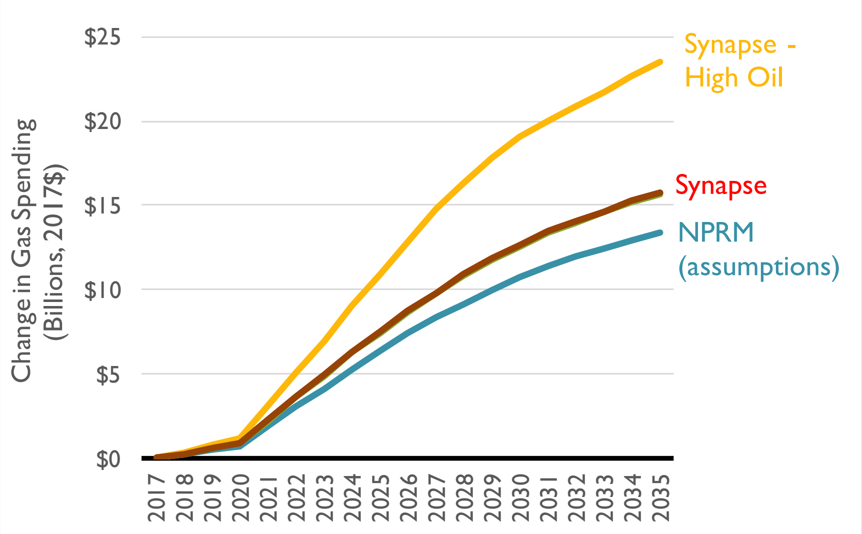


**Figure 21. Change in fuel spending draft rule – truck fleet (billions, 2017$)**