USC Price
Sol Price School of Public Policy

Antonio M. Bento
Professor of Public Policy and Economics
Sol Price School of Public Policy
Ralph and Goldy Lewis Hall 214
Los Angeles, CA 90089-0626
t. (213) 821-1762
e. abento@usc.edu

Written Testimony

Antonio M. Bento, PhD
Professor of Public Policy and Economics
University of Southern California

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"Trump's Wrong Turn on Clean Cars: The Effects of Fuel Efficiency Rollbacks on the Climate, Car Companies and California"
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Thank you Chair Rouda, Ranking Member Comer, and distinguished members of the subcommittee. My name is Antonio Bento, and I am a professor of public policy and economics at the University of Southern California. I am also a research associate of the National Bureau of Economic Research (NBER). Prior to joining the faculty of the University of Southern California in 2015, I was a tenured professor at Cornell University (2007-15), an assistant professor at the University of Maryland (2004-07) and an assistant professor at the University of California, Santa Barbara (2000-04). I am an applied microeconomist by training, with a research program in the areas of environmental, energy, and public economics. Most of my work consists of theoretical and empirical assessments of major environmental/energy public policy issues. For the past two decades, I have written on topics related to the design of climate change mitigation policies and the interaction of (newly) carbon pricing policies with the broader tax system; I have also examined issues related to the design and distributional impacts of federal gasoline taxes, as well as the effects of fuel economy standards and scrappage programs. During the past decade, in particular, I have developed models to study both consumers' decisions of purchasing and using vehicles, as well as automakers decisions to produce different types of vehicles. These 'equilibrium models', based on a classical paper (Bento et al. (2009)) published in the *American Economic Review*[1], remain the 'state of the art' in the profession and the ideal framework for evaluating the economic costs and benefits, as well as environmental impacts of fuel economy policies.

Directly related to today's hearing are two recent papers: First, a study published in *Science*, "**Flawed analyses of U.S. auto fuel economy standards**" - that I have co-authored with a group of distinguished scholars last December, following the administration's proposal to rollback the Clean Car Standards. Second, a recent study published as a NBER working paper titled "**Estimating the Costs and Benefits of Fuel Economy Standards**[2]". Given the relevance of the Science paper, I am attaching it to my testimony.

In this testimony, I briefly summarize some of the key findings from these studies, and describe how the 2018 Notice of Proposed Rulemaking (NPRM) has fundamental flaws and inconsistences, is at odds with basic economic theory and empirical studies, is misleading, and does not improve estimates of the costs and benefits of fuel economy standards beyond those in the 2016 analysis. To the best of my knowledge, given the substantial departure from a comprehensive protocol for benefit-cost analysis, my conclusion is that **a rollback of the clean car standards will not only not produce welfare gains, but instead result in serious unintended**

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[1] See: https://www.aeaweb.org/articles?id=10.1257/aer.99.3.667
[2] See: https://www.nber.org/papers/w26309

consequences including: (a) increases in greenhouse gas emissions; (b) increases in local air pollution; (c) a de-facto penalty on automakers who have been leaders in technological innovation. Further, California, and in particular the Los Angeles metropolitan area, will witness a deterioration of air quality, with potentially serious health impacts.

Major Modeling Flaws - An inadequate framework for measuring the costs and benefits of the clean car standards used in the 2018 NPRM

In the 2018 Science paper, my co-authors and I outlined the ingredients of a comprehensive protocol for the evaluation of fuel economy standards – one that builds on basic economic theory principles, and my earlier work (Bento et. Al (2005)). We note that the framework used in the 2018 NPRM analysis deviates substantially from a standard protocol for at least the following reasons: (a) it doesn't explicitly model consumer choices and tend to miss important trade-offs between general consumption, vehicle choice, and vehicle miles driven; (b) the modeling of the new and used car markets doesn't fully consider important interactions between these markets. As a result, important outcomes such as the *size of the fleet*, *fleet composition*, and *prices of vehicles*, are captured imperfectly; (c) because of these modeling flaws, in particular those outlined in (b), *the magnitudes* of the external costs and benefits are also incorrectly calculated. See more details in the attached paper.

Implications of these Major Modeling Flaws

- There are absurd differences in the costs and benefits of the 2022-2025 standards as calculated in the 2018 NPRM analysis, when compared with the 2016 analysis. Specifically, for the CAFE Standard, **the 2016 review finds a net benefit of $87.6 billion, whereas the 2018 analysis finds a net loss of $176.6 billion**. In other words, the proposed rollback would generate a net benefit based on the assumptions made in the 2018 analysis; For the GHG emissions standards the 2016 analysis finds a net benefit of $97.2 billion, whereas the 2018 analysis finds a net loss of $200.6 billions. As discussed in the Science paper attached, to the best of my knowledge, there is no logical justification for the dramatic change in the calculation of the costs and benefits, and it is still my believe that the current standards do pass cost-benefit analysis, and that, there is no economic reason to roll them back.

The differences in the calculation of costs and benefits between the 2016 and 2018 analysis are based on:

Misguided Parameter choices

- The 2018 analysis doubles the magnitude of the so-called '*rebound effect*', that is the additional driving that takes place due to the reduction in the per-mile costs of more fuel-efficient cars. This assumption can lead to unfounded concerns about unintended safety consequences of the current standards, since **this over-estimate of driving leads to a total of 12,700 additional fatalities**. To the best of my knowledge, there is no scientific evidence that supports this effect.
- Domestic versus global benefits from reducing carbon emissions – the 2018 analysis accounts only for the domestic benefits from reducing carbon emissions. This effectively scales down the social cost of carbon from $48 per metric ton to $7 per metric ton, **reducing GHG benefits from $27.8 billion in 2016 to $4.3 billion in 2018**. To the best of my knowledge, there is no scientific reasons in favor of altering the broadly accepted notion that the calculation of the benefits from reducing carbon emissions should be global, given the interdependencies between economies, including the US economy.

Ad-hoc and incorrect Modeling of the interaction between new and used cars

- A major difference between the 2016 and 2018 analysis is the projection of the total fleet size of cars and light-duty trucks. Economic theory predicts that tighter standards make new vehicles more expensive. This also translates into more expensive used cars. As a consequence the total fleet size should decrease over time, as a result of the tightening of the fuel economy standard. By contrast, **the 2018 proposal argues that the rollback in standards will shrink the overall fleet by 6 million vehicles in the year 2029, compared with the current standards**. This is simply inconsistent with basic economic principles. To the best of my knowledge, this inconsistency is a result of an ad hoc integration of a newly developed vehicle scrappage model with the NHTSA's Volpe model. Others who have examined the structure of the models used in the 2018 NPRM have made similar comments (see comments submitted to the docket)

- It is important to understand the implications of projecting an incorrect fleet size:
    - Total Driving should increase (as opposed to decrease) with the rollback, since driving scales up with fleet size. Increased driving translates into increases in gasoline consumption and the external effects of GHG emissions, local air pollution, traffic fatalities, congestion, and energy security. To the best of my knowledge, the effect of the rollback on these outcomes will be larger than reported in the 2018 analysis, potentially by substantial amounts.
    - Crash fatalities and injuries should increase (as opposed to decrease) with the rollback. Yet, the 2018 analysis concludes that the rollback will result in a $90.7 Billion gain from reduced fatalities and property damages. In the best-case scenario, where we just add back the missing 6 million used cars, this gain will likely fall to near zero.

When we correct for all these flaws, we demonstrate in the Science paper that, at least $112 billion was discarded in the 2018 analysis. For the rollback to have negative effects, one only needs to reduce the 2018 technology costs by 26%, which are still doubled the costs considered in the 2016 analysis.

In conclusion, to the best of my knowledge, there is no valid economic reason to justify the proposed rollback.

POLICY FORUM

ENVIRONMENTAL ECONOMICS

Flawed analyses of U.S. auto fuel economy standards

A 2018 analysis discarded at least $112 billion in benefits

By **Antonio M. Bento**[1,2], **Kenneth Gillingham**[3,2], **Mark R. Jacobsen**[4,2], **Christopher R. Knittel**[5,2], **Benjamin Leard**[6], **Joshua Linn**[7], **Virginia McConnell**[6], **David Rapson**[8], **James M. Sallee**[9,2], **Arthur A. van Benthem**[10,2], **Kate S. Whitefoot**[11]

In addition to greenhouse gas emissions and fuel economy, analyses must also consider effects on pollution, safety, and traffic congestion.

Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emissions standards for passenger vehicles and light trucks have long been a centerpiece of the U.S. strategy to reduce energy use and GHG emissions and increase energy security. Under the authority of the Energy Independence and Security Act, the Environmental Protection Agency (EPA), and the National Highway Traffic Safety Administration (NHTSA) jointly set GHG and CAFE standards to reach 55 miles per gallon by 2025. A 2016 draft technical assessment report (TAR) affirmed by the EPA in January 2017 concluded that the 2022–2025 standards were technologically feasible and that benefits far exceeded costs. But under the current administration, those agencies are now challenging that conclusion in a 2018 Notice of Proposed Rulemaking (NPRM), which proposes freezing standards at model year (MY) 2020 levels through 2025. Its analysis finds that the costs of the previous standards now exceed benefits. With the agencies currently in the process of determining whether the rule should be finalized, we describe how the 2018 analysis has fundamental flaws and inconsistences, is at odds with basic economic theory and empirical studies, is misleading, and does not improve estimates of costs and benefits of fuel economy standards beyond those in the 2016 analysis.

A COMPREHENSIVE PROTOCOL

A benefit-cost analysis (see table S1) for fuel economy standards grounded on basic economic principles must consider the behavior of consumers and automakers as well as keep account of several externalities (*1*). It must consider a range of parameter values and assumptions to account for inherent uncertainty as well as the impact of related policies that determine the relevant baseline against which the standards are compared.

Modeling consumer behavior should include the purchase of general goods and new or used vehicles. Consumers trade off vehicle prices for various vehicle attributes (for example, performance, safety features, seating capacity, and so on). They also decide how much to drive and whether to keep or scrap their older vehicles.

A comprehensive analysis would allow automakers to comply with standards by adjusting vehicle prices, improving fuel economy, and altering performance and other vehicle attributes (*2–5*). It would also recognize that technology is determined by automaker investments, while accounting for learning-by-doing and knowledge spillovers that, over time, may lower the compliance costs.

Modeling of the interaction between new and used vehicle markets is critical to determine the resulting size of the total fleet and its composition, as well as the prices of vehicles (relative to the price of other goods). Prices, fuel economy, and other attributes determine the total cost of ownership, which affects total vehicle miles traveled (VMT), as well as willingness to pay for vehicles (*1*, *6*).

A comprehensive protocol should also consider costs and benefits that arise from "external effects," including GHG emissions, energy security, local air pollution, safety, and traffic congestion (*7*), which are affected by fleet size and its composition and the total number of miles driven.

In the case of safety, four additional outcomes are relevant: changes in vehicle weights and sizes, distribution of weights and sizes in the entire fleet, distribution of vehicle vintage, and sorting of individuals into vehicles on the basis of their risk preferences, risk profiles, and preferences for other vehicle attributes (*8–10*).

Valuation parameters are critical for converting impacts into costs and benefits. The value of a statistical life is used to value fatalities, whereas the social cost of carbon is used for valuing the benefits of reduced gasoline use (*11*, *12*). Other valuation parameters reflect the value of energy security and the health costs of tailpipe emissions. A comprehensive protocol should also account for other factors, including changes in gasoline prices over time.

TWO FLAWED ANALYSES

Both the 2016 and 2018 analyses deviate from the comprehensive protocol outlined above because they do not explicitly model consumer choices and tend to miss important trade-offs between general consumption, vehicle choice, and VMT. On the supply side, the modeling of the new and used car markets does not fully consider important interactions between these markets. As a consequence, multimarket adjustments, and resulting outcomes such as the size of the fleet, fleet composition, and prices of vehicles, are captured imperfectly. Incomplete accounting for such adjustments also affects the magnitudes of the external costs and benefits.

The 2018 analysis did attempt to incorporate several channels of adjustment that were missing from the 2016 TAR (see table S1, fourth column). However, the most impactful channels were added in an ad hoc way that runs afoul of the proposed protocol outlined above, existing research, and basic economic principles. As a result, the changes in the 2018 NPRM are misleading. Although we do not endorse the 2016 TAR, the 2018 analysis failed to advance our understanding of the true costs and benefits of fuel economy standards.

PHOTO: ISTOCK.COM/PLHERRERA

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[1]University of Southern California, Los Angeles, CA, USA. [2]National Bureau of Economic Research, Cambridge, MA, USA. [3]Yale University, New Haven, CT, USA. [4]University of California, San Diego, CA, USA. [5]Massachusetts Institute of Technology, Cambridge, MA, USA. [6]Resources for the Future, Washington, DC, USA. [7]University of Maryland, College Park, MD, USA. [8]University of California, Davis, CA, USA. [9]University of California, Berkeley, CA, USA. [10]University of Pennsylvania, Philadelphia, PA, USA. [11]Carnegie Mellon University, Pittsburgh, PA, USA. Email: abento@usc.edu

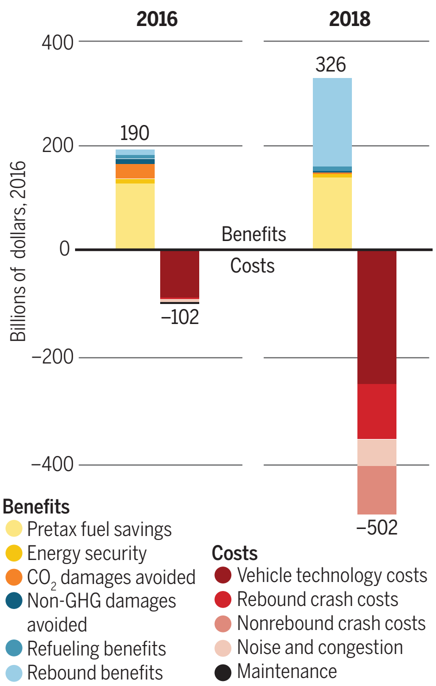
There are stark differences between the costs and benefits assigned to the 2022–2025 standards in the 2016 and 2018 analyses, reflecting differences in assumptions. The figure shows the costs and benefits from the affirmed 2022–2025 CAFE standards, relative to the proposed rollback levels as calculated by the agencies [see supplementary materials (SM) section G for the GHG emissions standards]. To interpret impacts of a rollback of the standard in the context of the figure, one should change the signs of all costs and benefits. For the CAFE standard, the 2016 review finds a net benefit of $87.6 billion, whereas the 2018 analysis finds a net loss of $176.6 billion. Or, in other words, the proposed rollback of the standard (relative to existing levels) would generate a net benefit based on the assumptions made in the 2018 analysis and a net loss based on the 2016 analysis; for the GHG emissions standard, the 2016 review finds a net benefit of $97.2 billion, whereas the 2018 analysis finds a net loss of $200.6 billion (see the SM for details).

The 2018 analysis reports benefits that are roughly twice as high as those in the 2016 analysis, primarily from benefits owing to lower driving costs that increase miles traveled that consumers value (that is, the rebound effect). The 2018 analysis doubles the magnitude of the rebound effect despite recent literature estimating smaller rebound effects (see the SM for details). Whereas in the NPRM analysis, the higher rebound effect hardly affects net benefits—as additional benefits from avoided car crashes under the rollback are offset by lost benefits from reduced VMT—it doubles the number of avoided fatalities generated by this effect, contributing to a total of 12,700 lives. The assumption regarding the higher rebound effect may lead to unfounded concerns about unintended safety consequences of the current standards.

Accounting only for domestic benefits from reducing carbon emissions (ignoring international benefits) scaled down the social cost of carbon from $48 per metric ton to $7 per metric ton, reducing GHG benefits from $27.8 billion in 2016 to $4.3 billion in 2018. A more minor difference is that the analyses make slightly different assumptions about the extent to which consumers value future fuel savings from driving a more fuel-efficient car (see SM section C for further discussion of the impact on net benefits).

2016 and 2018 benefit-cost analyses of CAFE standards

Stark differences between the 2016 and 2018 estimates reflect fundamental flaws and inconsistencies in the 2018 analysis. See supplementary materials.



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SIX MILLION MISSING USED CARS

A central difference between the 2016 and 2018 reports is the projection of the total fleet size of cars and light-duty trucks. Economic theory predicts that tighter standards make new vehicles more expensive, on average. This also translates into more expensive used vehicles, on average, because they are substitutes for new vehicles (*6*). As a consequence, as standards increase vehicle prices, total fleet size should decrease over time. Conversely, a rollback should lead to increased demand for vehicles, resulting in a larger fleet that will be newer, on average.

By contrast, the 2018 proposal argues that the rollback in standards will shrink the overall fleet by 6 million vehicles in the year 2029, compared with the current standards. This is inconsistent with basic economic principles. If prices of vehicles decrease (relative to other general-purpose goods), we expect more individuals to purchase vehicles and drive them rather than use other modes of travel. The 2018 NPRM analysis reaches the opposite conclusion based on ad hoc integration of a newly developed vehicle scrappage model with the NHTSA's Volpe model (the CAFE Compliance and Effects Modeling System).

We have identified two major shortcomings of this approach. First, this newly developed model departs substantially from state-of-the-art vehicle scrappage models (*6*, *13*) (see the SM for further details). Second, in relation to the comprehensive framework, the 2018 NPRM does not account for changes in used vehicle prices that result from interactions between new and used car markets as a result of the standard (see the SM for additional discussion). As a result, this new model violates simple economic principles; leads to misleading conclusions related to the overall size of the fleet, fleet composition, and the amount of scrappage; and undermines EPA and NHTSA modeling efforts to improve the understanding of the costs and benefits of fuel economy standards.

These 6 million "missing" vehicles have important implications. A larger fleet leads to higher miles driven, gasoline use, and external costs. Total driving, excluding the rebound effect, should increase (as opposed to decrease) with the rollback relative to keeping the previous standards. Driving scales with fleet size, and newer cars are driven more. As VMT increases, gasoline consumption and the external effects of GHG emissions, local air pollution, traffic fatalities, congestion, and energy security of the rollback will be larger than reported in the 2018 analysis, potentially by considerable amounts.

Crash fatalities and injuries can increase (as opposed to decrease) with the rollback. The 2018 analysis concludes that the rollback will result in a $90.7 billion gain from reduced fatalities and property damages, a result driven almost exclusively by a 2.4% reduction in fleet-wide VMT (changes in fleet composition play a minor role in the 2018 analysis). If we hold fleet size fixed (adding back the missing 6 million used cars), this $90.7 billion gain is likely to fall to near zero. This is a conservative calculation and should be interpreted as a lower bound, because we anticipate that rollback would cause the fleet to grow, possibly driving this term below zero (see the SM for further details).

COMPLIANCE COST INCONSISTENCIES

The EPA and NHTSA estimate costs of hundreds of different fuel-saving technologies and model how manufacturers will add these technologies and combinations of technologies using least-cost algorithms. For the 2016 TAR analysis, the estimates of costs by the EPA for GHG standards are less than half of the costs for the same rule estimated by the NHTSA for CAFE standards. This is in part because the EPA assumes that California and other states' Zero Emission Vehicle (ZEV) mandate will be in place in future years. With many electric vehicles already in the fleet, the incremental cost of meeting the higher fuel economy standards of the federal rule is considerably lower. The NHTSA implicitly assumes that there is no ZEV mandate, which leads to higher calculated costs. The 2018 NPRM does the same.

For a clearer comparison of technology costs, we focus on differences in the NHTSA's estimates of costs in the 2016 and 2018 analyses (see the figure). According to the NHTSA, the 2018 costs are more than two times higher than the earlier TAR costs. Some of the cost differences are a result of plausible changes in economic conditions, such as an increase in future new vehicle sales owing to higher income growth and lower gasoline prices. Another important difference, however, is due to the fact that the agencies changed the model years affected by the standards in the 2018 analysis. In the 2016 analysis, the costs of the MY 2022–2025 standards are assessed relative to a baseline fixed at MY 2021 levels. By contrast, the 2018 NPRM argues that the standards should be frozen a year earlier and compares the costs of meeting the existing standards for MY 2021–2025 relative to standards fixed at the MY 2020 level. The agencies claim that the previous standards are no longer feasible and appropriate, but they do not even examine the technology costs for this change in the standards in the 2018 assessment of alternatives. We can show, however, that this change accounts for roughly 12% of the difference in costs for the 2016 and 2018 standards (see the figure; for more discussion of this point, see the SM].

Notwithstanding these differences, we still find that reported per-vehicle costs with the GHG emissions standards are about 80 to 150% higher for MY 2022–2025 vehicles in the 2018 proposal than in the 2016 NHTSA analysis (see fig. S3 for details). In addition to the difference in model years being regulated, four other main factors account for these cost differences.

First, automakers can comply with the regulations by transferring fuel economy “credits” between their passenger car fleet and their light-truck fleet, so that if one fleet overcomplies with the regulations, the other can undercomply within some limit. Credit transferring is also possible across years, so that if an automaker exceeds fuel economy performance in one year, it can meet a less stringent standard in another year. But these flexibilities were not included in the 2018 analysis for MY 2021–2025 (although credit transferring was possible from years before 2021), raising the estimated costs. The NHTSA is prohibited by statute from considering all of these flexibilities in the setting of standards, whereas the EPA is not subject to this restriction. In the 2016 TAR, compliance flexibilities were included in the NHTSA analysis but did not influence the setting of the standards.

Second, the 2018 analysis removed some projected future technology options that were considered in the 2016 analysis (for example, Atkinson engines with cylinder deactivation and exhaust recirculation). Omitting these projected lower-cost options, the 2018 analysis predicts that a substantially higher deployment of more-expensive technologies is necessary to meet the standards: 24% of vehicles in the 2018 analysis are projected to be strong hybrids by MY 2025, whereas only 2.6% are in the 2016 analysis.

Third, the analysis assumes that longer time periods are required to redesign many vehicles to meet the standards in a given year, requiring manufacturers to add fuel-saving technologies earlier, thereby incurring higher costs for more years.

Fourth, the specified costs for electrified vehicles are considerably higher (20 to 50%) than in the 2016 analysis owing to different battery assumptions (for example, electrode thickness limited to 100 microns) and including additional vehicle electrification components (for example, liquid cooling systems) recommended by the National Academies (*14*). In summary, although some of the changes in technology assumptions in the 2018 analysis are plausible, overall it uses pessimistic assumptions of future technology availability and performance compared with the 2016 analysis.

SAFETY VALVE INSTEAD OF ROLLBACK

We conclude that the 2018 analysis has several fundamental flaws and inconsistencies. In addition to the points we have raised, others have articulated why a global, rather than a domestic, social cost of carbon is the appropriate parameter to value GHG emissions reductions (*11*, *12*), and we agree. Using a global estimate of the social cost of carbon and the correct impact of changes to total fleet size reduces the net benefits of the rollback for the CAFE standard (from $176 billion to $64 billion). Or, in other words, at least $112 billion was discarded in the 2018 analysis. Furthermore, of this, at least $88.3 billion comes from accounting for the missing 6 million cars. For the rollback to have negative net benefits, one only needs to reduce the 2018 technology costs by 26%, which still doubles the costs from the 2016 analysis; using the technology costs from the 2016 analysis implies that the standard will have large positive net benefits. In general, these conclusions also apply to the GHG emissions standard (see the SM for further details).

Under any scenario, the case for a rollback could be made if compliance costs are sufficiently high, but both the 2016 TAR and 2018 NPRM have likely overestimated compliance costs. Neither analysis considers the full extent of options that manufacturers have available to respond to these policies, including changes in vehicle prices, performance, and other attributes. Relative to the 2016 TAR, the 2018 NPRM seems to compound this mistake, leading to greater overestimates of compliance cost by not accounting for the full extent of banking and borrowing credits and by using pessimistic assumptions regarding technology costs.

Given the substantial departure from a comprehensive protocol for benefit-cost analysis, we cannot conclude that the rollback will produce welfare gains, and we instead predict that it will result in unintended consequences. For example, in anticipation of higher standards, automakers accumulated CAFE credits, which they intended to use in the future as a strategy for lowering compliance costs. A rollback of the standard would lead to a de facto devaluation of these credits, penalizing automakers who have been leaders in technological innovation.

Furthermore, economic theory predicts that, for the same level of standard, costs of compliance decline as a result of learning-by-doing and spillover benefits from technology development across automakers. Therefore, we see no economic justification to keep the standard flat from 2020 to 2025, even ignoring the external societal benefits of the standard. Instead, standards should increase over time in stable and predictable ways.

We certainly recognize the inherent uncertainty in estimating costs of compliance through technologies, but we recommend the introduction of a safety valve to address this concern, rather than a rollback. Safety valves, common in cap-and-trade programs, allow firms to purchase compliance credits at a predetermined price, effectively capping compliance costs and allowing for less technology improvement if it turns out to be highly expensive (*15*). A rollback is an unnecessarily blunt way to achieve the same goal and introduces regulatory uncertainty into an industry that needs to make long-run technological investments for the future. ■

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SUPPLEMENTARY MATERIALS

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Science

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Supplementary Materials for

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Antonio M. Bento*, Kenneth Gillingham, Mark R. Jacobsen, Christopher R. Knittel,
Benjamin Leard, Joshua Linn, Virginia McConnell, David Rapson, James M. Sallee,
Arthur A. van Benthem, Kate S. Whitefoot

*Corresponding author. Email: abento@usc.edu

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This PDF file includes:

Supplementary Text
- A. A framework for evaluating the effects of tightening CAFE and GHG emissions standards
- B. An explanation of the difference between CAFE vs. GHG standards
- C. Additional discussion on the valuation of fuel economy and the rebound effect
- D. Additional explanation for the difference in costs of compliance with technology between the 2016 TAR and 2018 NPRM
- E. Discussion of the inconsistencies in the NPRM's vehicle turnover modeling
- F. Explanation of main benefit-cost tables in the 2018 *Notice of Proposed Rulemaking*
- G. Data for Figure 1 in the main text about the costs and benefits from the 2016 vs. 2018 analyses
- H. Additional references

Figs. S1 to S4
Tables S1 to S7 (also provided in an Excel file)

Other Supporting Online Material for this manuscript includes the following:
(available at www.sciencemag.org/content/362/6419/1119/suppl/DC1)

Supporting Data: Tables S1 to S7 and Data for Figures (Excel)

Supplementary Text

A. A framework for evaluating the effects of tightening CAFE and GHG emissions standards

In this appendix we present a framework for a benefit-cost analysis of the effects of tightening CAFE and GHG emissions standards that is grounded on basic economic principles. We start by laying out in Table S.1 the various outcomes and channels of adjustments that a complete benefit-cost analysis would take into account. We group the various channels under effects on consumers, effects on automakers, and external effects. The table also lists the anticipated direction of the impact as positive, negative, close to zero, or ambiguous. We further note whether or not these channels were incorporated in the 2016 TAR and the 2018 NPRM.

It is currently not practically or computationally feasible to model each channel at a high level of detail or with highly granular data. However, benefit-cost analysis must be based on a carefully constructed model of the behavior of both consumers and automakers that avoids logical contradictions with economic principles.

On the consumer side, to ensure that the estimated costs and benefits hold up to this requirement, it is important that the analysis be based on a consumer choice model which is sufficiently rich to capture choices between cars of different ages, classes, fuel economy and other attributes (even though a fairly high level of aggregation might be inevitable). Prices, fuel economy, and other attributes determine the total cost of ownership, which affects total vehicle miles traveled as well as willingness to pay for vehicles. The consumer choice model should also properly and explicitly model the interaction between new and used vehicle markets, as this will determine the resulting size of the total fleet and its composition, as well as the prices of vehicles (relative to the price of other goods).

The consumer model needs to be paired with a model that allows automakers to comply with standards by adjusting vehicle prices, improving fuel economy, and altering performance and other vehicle attributes. It also would recognize that technology is determined by automaker investments, while accounting for learning-by-doing and knowledge spillovers that over time may lower the cost to manufacturers for complying with the standards.

Finally, the analysis needs to calculate a wide range of external costs and benefits that result from changes in the size and composition of the fleet, and total driving, including greenhouse gas emissions, energy security, local air pollution, safety, and traffic congestion.

Arriving at a credible central estimate of the net benefits is therefore an involved exercise, but one that EPA and NHTSA are required to perform. It is the role of the scientific community to help assure that such analysis is based on the best evidence available.

A comprehensive protocol would recognize uncertainties—about not just future outcomes, but also modeling choices and behavioral parameters—and conduct sensitivity analysis to identify factors that could most influence the final analysis. We emphasize that there is substantial uncertainty as to the magnitudes of many of the costs and benefits to consumers, firms and society at large.[1] The resulting central estimates of costs and benefits must therefore be subjected to extensive sensitivity analysis using a range of parameter values and model assumptions. Such analysis does justice to the reality that every framework has limitations. In practical settings such as CAFE standards where many channels and outcomes need to be quantified, sensitivity analysis becomes even more important, and it should not be treated as an afterthought.

For each parameter, the estimates and confidence intervals from the most rigorous academic studies available should guide the relevant range. Key parameters include valuation parameters for external effects, such as the value of a statistical life, the non-fatal health effects from pollution (i.e., the specification of dose-response functions; especially whether one assumes thresholds), the social cost of carbon (e.g., does the analysis use a domestic or a global estimate), parameters that relate to the safety impacts of fleet changes, congestion, energy security, visibility, and more.

On the consumer side, the preferred protocol should document the sensitivity to important factors such as changes in gasoline prices over time, implicit consumer discount rates, the degree to which consumers are risk averse, the rebound effect, assumptions regarding vehicle lifetimes, how consumers decide to scrap their vehicles as used vehicle resale values change, to what extent consumers will switch to other modes of transportation if vehicles become more expensive or less appealing, perceptions of differences in safety, and understanding of the behavioral options for dealing with such differences.

On the producer side, sensitivity analysis related to assumptions about the cost of technologies, learning effects, and how automakers will adjust innovation and pricing decisions in response to standards improve our understanding of automakers' behavior. In addition, assumptions about the interaction with other related regulations may have important implication for the net benefits of the policy.

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[1] There is also uncertainty about how standards affect tax revenues, which are just transfers from one economic party to another, as well as uncertainty about effects on the trade deficit (also a transfer). Transfers are not changes in social welfare, and thus should thus be netted out in a benefit-cost analysis, but we recognize of course that they may matter for political feasibility.

Besides varying one parameter at a time, one can perform a scenario analysis in which multiple parameters are varied in an internally consistent direction. Alternative scenarios will be particularly useful in bounding the role of consumer and producer behavior, as well as the magnitudes of the external effects.

Finally, a model for benefit-cost analysis can be validated using out-of-sample predictions based on historical data and by comparing them against more recent realized market outcomes that are not used to parameterize or calibrate the model.

The preferred framework that we have laid out will produce a central case estimate of the overall net benefits of a fuel-economy standard that should not result in logical contradictions, such as effects that go in directions that economic theory and intuition would rule out. Obviously, an extensive sensitivity analysis as proposed above may yield a wide range of net benefits that should be presented to policymakers, but proper modeling choices will again ensure that even large variations in parameters and assumption result in economically coherent outcomes. This should provide policymakers with the best possible information to reach an informed decision.

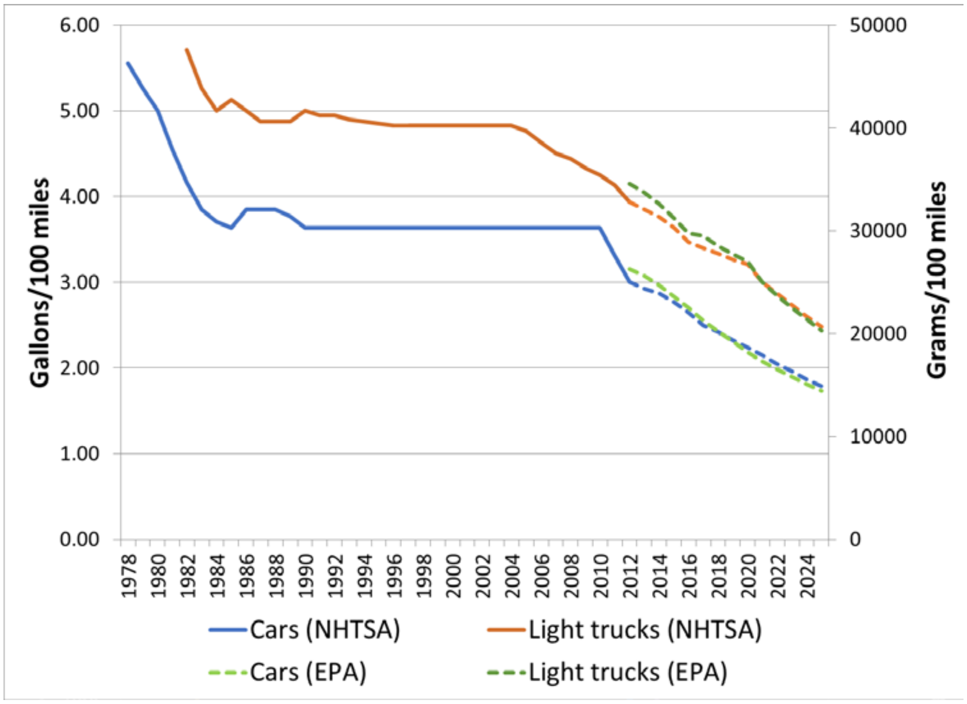
	Outcome	Channel of Adjustment	Direction of Impact	Adjustment Captured in 2016 TAR?	Adjustment Captured in 2018 NPRM?	Cost/Benefit (Key Parameters)
Consumers						***Consensus: negligible or modest cost***
	Affordability/price of vehicles	Increased compliance costs are passed on to consumers in the form of higher vehicle prices; used car prices increase	Negative	Partial	Yes	Cost
	Fuel savings	Increased fuel economy leads to fuel economy savings	Positive	Yes	Yes	Benefit (depends on extent of 'undervaluation' of fuel-economy savings and payback time of new fuel-economy technologies)
	Vehicle attributes	Standard may push consumers away from their desired products	Negative	No	No	Cost (depends on relative valuation of vehicle attributes)
	Mobility	Increased fuel economy allows for additional driving without increased private costs (rebound effect)	Positive	No	Yes	Benefit (depends on magnitude of rebound)
Automakers						***Consensus: unknown; probably negligible or modest cost***
	Changes in profits	Standard increases compliance costs; part of the compliance cost may be borne by the automaker	Negative	Yes	Yes	Cost (value of CAFE credits provides anecdotal evidence of modest cost)
		Induced innovation and learning-by-doing lowers compliance costs through time	Positive			Benefit (induces gains from technological innovation that would have not happened otherwise)
		Spillover effects in innovation across automakers lowers compliance costs through time	Positive			Benefit
External Effects						
	Total Reduction in Gasoline Use					***Consensus: benefit***
	Total fleet size	Increases in the price of vehicles lead to consumer substitution towards other goods	Positive	No	Partial	Depends on extent of reduction of the fleet and valuation of GHG emissions savings and energy independence
	Fleet composition (new/used), holding VMT constant	Increases in the price of new vehicles leads to substitution towards used vehicles and reduced scrappage	No impact	No	Partial	
	Vehicle miles travelled	Rebound effect - reductions in the cost per mile of driving due to increased fuel economy	Negative	Yes	Yes	Magnitude depends on estimate of rebound effect
	Safety: Increased Fatalities					***Consensus: unknown; likely modest cost or benefit***
	Total fleet size	Increases in the price of vehicles lead to consumer substitution towards other goods	Positive	No	Partial	Magnitude depends on value of statistical life and total fatalities
	Fleet composition change, holding other factors constant	Increases in the price of new vehicles lead to substitution towards used vehicles (less safe)	Negative	No	Partial	
	Sorting of individuals into cars (depending on their risk preferences)		Ambiguous	No	No	
	Vehicle attribute changes; downweighting, downsizing	Automakers downweight the initial lighter vehicles	Positive	Yes	Yes	
	Distribution of vehicle weights	Automakers competition and interactions with used market determine new weight distribution	Positive	No	No	
	Vehicle miles travelled	Rebound effect - reductions in the cost per mile of driving due to increased fuel economy	Negative	Yes	Yes	
	Local Air Pollution					***Consensus: ambiguous?***
	Total fleet size	Increases in the price of vehicles lead to consumer substitution towards other goods	Positive	No	Partial	Valuation of local air pollution improvements are typically higher than GHG emissions
	Fleet composition change, holding other factors constant	Increases in the price of new vehicles leads to substitution towards used vehicles and reduced scrappage	Negative	No	Partial	
	Vehicle miles travelled	Rebound effect - reductions in the cost per mile of driving due to increased fuel economy	Negative	Yes	Yes	
	Congestion					***Consensus: ambiguous?***
	Total fleet size	Increased in the price of vehicles leads to consumer subtstition towards other goods	Positive	No	Partial	Valuation of congestion is typically higher than GHG emissions
	Fleet composition change, holding other factors constant	Increases in the price of new vehicles leads to substitution towards used vehicles and reduced scrappage	No impact	no	Partial	
	Vehicle miles travelled	Rebound effect - reductions in the cost per mile of driving due to increased fuel economy	Negative	Yes	Yes	
Interactions with Other Policies				Partial	No	

Table S.1: Major Pathways of Effects of CAFE Standards and How They Would Influence the Costs and Benefits

B. An explanation of the difference between CAFE vs. GHG standards

Since 2012, NHTSA and EPA have jointly set standards for light-duty vehicles. NHTSA sets standards for vehicle fuel economy in terms of miles per gallon, while EPA sets standards for vehicle greenhouse gas emissions in terms of grams per mile of CO_2-equivalent GHG emissions. Since a vehicle's fuel economy is inversely proportional to its fuel use and emissions, the regulations are in effect setting different requirements for the same vehicle attribute. NHTSA and EPA have designed each standard in a way that the annual requirements are roughly harmonized, so that a vehicle's standard for fuel economy expressed as CO_2 grams per mile is nearly identical to the EPA grams per mile standard. Figure S.1 illustrates this harmonization by plotting both standards set under the Obama Administration, with NHTSA's fuel-economy standard converted to gallons of gasoline per 100 miles.

Figure S.1: Historical CAFE and Projected Obama Administration CAFE and EPA GHG Standards



Note: The original source of this figure is Leard and McConnell (2017).

The joint standards provide similar flexibilities for manufacturer compliance. Both allow manufacturers to earn credits from over-compliance, which can be banked for future use (the banking provision), sold to other manufacturers (the trading provision), or used to comply with a class of vehicles that is in under-compliance (the averaging provision). The details of each type of flexibility, however, differ. While NHTSA's CAFE program allows banked credits to be used for up to 5 years, the EPA program initially had a longer bank window for credits earned through 2016. Credits earned during this period are scheduled to expire in 2022. This has implications for the relative stringency of the two programs, as CAFE credits earned in the early part of this decade will have expired by the end of the decade, while equivalent EPA credits will still be available to use through 2021. This effectively makes the CAFE program more stringent in the coming years.

Another difference in how the agencies have designed the compliance flexibilities is for the averaging provision. The NHTSA CAFE program limits how many credits earned from a manufacturer's car or truck fleet can be used for their other fleet, while the EPA program does not have averaging limits. Beginning in the model year 2018 compliance year, the CAFE program limits averaging to 2.0 mpg per manufacturer, which restricts the extent of under-compliance in either vehicle (car or light truck) category.

A final key difference is that the NHTSA CAFE program has an explicitly stated fine for under-compliance: $14/tenth mile per vehicle in under-compliance. This fine provides manufacturers with an alternative compliance strategy in the case where the cost of meeting the standard is sufficiently large. The EPA GHG program has no explicit fine for under-compliance but in principle the fine could be as high as $37,500 per car for violation of the Clean Air Act.

In the remainder of these supplementary materials, we follow the relevant regulatory documents and show costs and benefits for both standards. Our conclusions are very similar regardless of the standard under consideration.

C. Additional discussion on the valuation of fuel economy and the rebound effect

Assumptions about how consumer value fuel economy exist within both regulatory analyses. Both the 2016 TAR and 2018 NPRM implicitly assume that consumers undervalue savings from lower gasoline costs resulting from driving a fuel-efficient car. Both analyses operationalize this assumption through manufacturers' beliefs about consumer preferences – firms believe that consumers undervalue savings when deciding what technologies to add. Note that these beliefs on the part of manufacturers would affect their expected profit-maximizing level of fuel economy, and are a primary mechanism via which the model predicts a suboptimal baseline of fuel economy. We further emphasize that, while the undervaluation in the 2016 and 2018 proposed rules enters through manufacturers' beliefs, both analyses assume that consumers enjoy the full benefit of the fuel savings when the reports calculate the gasoline savings from a more stringent standard (see line 7 in Tables S.5 and S.6 below).

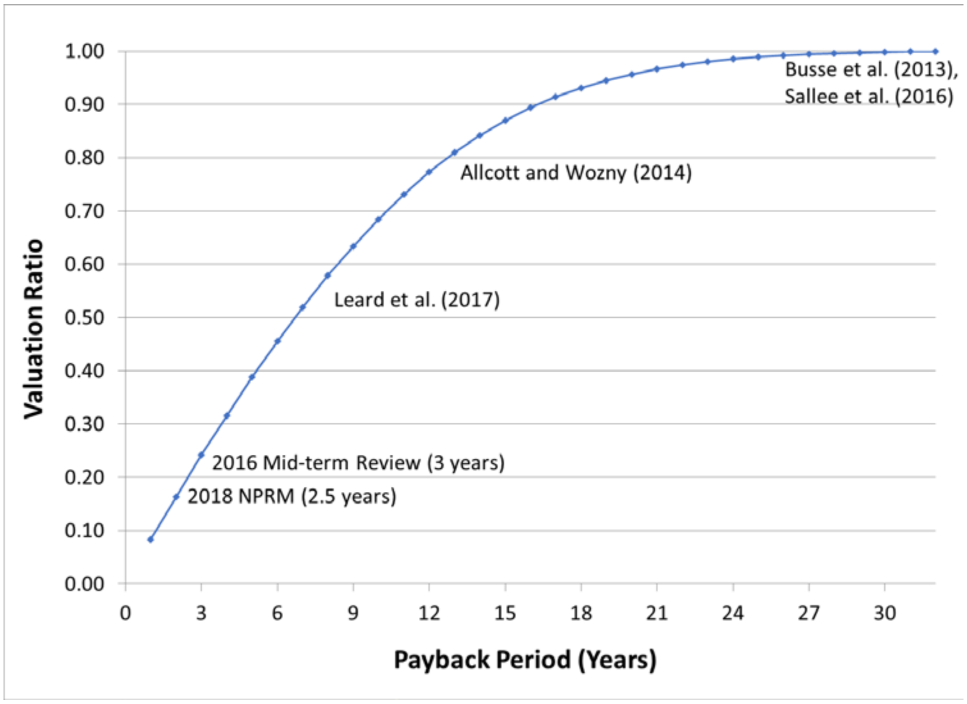
Both 2016 TAR and 2018 NPRM assume substantial undervaluation (details below), but their assumptions are so close that this cannot explain much of the difference between these two cost-benefit analyses. Nonetheless, we discuss how the degree of undervaluation assumed in the analyses compares with estimates from the academic literature.

Figure S.2 illustrates the mechanical relationship between two methods for quantifying how vehicle buyers value fuel costs. The first method is shown on the vertical axis and it equals the ratio of consumer valuation of fuel cost savings and actual fuel cost savings. Consumer undervaluation of vehicle lifetime fuel costs is represented by a ratio that is less than one. Estimates of consumer valuations for fuel economy contain a range of uncertainty (EPA, 2018; Greene et al., 2018). Several recent studies have been able to take advantage of detailed transaction-level data and show a range for the valuation ration of between 50-100% (Allcott et al., 2014; Sallee et al., 2016; Leard et al., 2017). The valuation ratio can also be inferred from other studies, such as Busse et al. (2013). The second method is shown on the horizontal axis and is referred to as the payback period method, which quantifies the number of years of fuel costs that vehicle buyers value when making a purchase. If consumers undervalue vehicle lifetime fuel costs, then the payback period will be less than the expected vehicle lifetime.

Since both methods measure consumer valuation of fuel costs, there exists a mapping between the two. Given assumptions about private discount rates, fuel prices, and vehicle miles traveled schedules, this mapping is unique in the sense that each payback period is equivalent to a unique valuation ratio and vice versa. We compute this mapping using assumptions on private discount rates, fuel prices, and vehicle miles traveled schedules based on data and assumptions from Leard et al. (2017). We plot the mapping in Figure S.2. In this figure, we indicate where recent empirical studies land on the plotted relationship. For example, Leard et al. (2017) find that new vehicle buyers are willing to pay 54 cents per dollar of fuel cost savings, represented by a valuation ratio of 0.54. This valuation ratio maps to a payback period of about 7 years.

The 2016 TAR assumes a 3-year payback period and the 2018 NPRM assumes a 2.5-year payback period. These map to valuation ratios of 0.24 and 0.20, respectively. As indicated by Figure S.2, these implied valuation ratios are below those found in recent empirical studies. We reiterate, however, that the agencies' analysis assume that fuel savings fully accrue to consumers; the lower valuation ratio reported in Figure S.2 pertains to the beliefs on the part of the automakers.

Figure S.2: The Mapping between the Valuation Ratio and Payback Period



The assumed payback period in the proposed rulemaking affects benefits and costs by affecting the technologies that are adopted in the absence of binding standards. The longer the payback, the more technology gets adopted. Consequently, increasing the payback period raises average fuel economy in the world of no CAFE. In other words, longer payback period means lower benefits and lower costs of tighter standards. Since the model applies the most cost-effective technologies first, longer payback period means lower net benefits for more stringent fuel-economy standards.

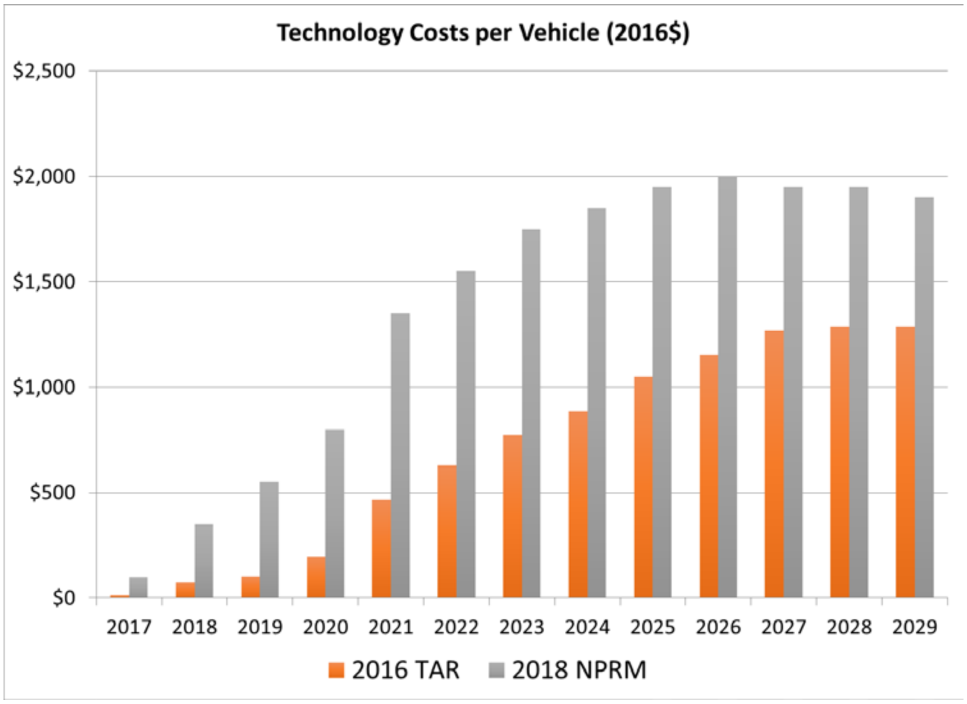
Another difference between the two analyses is that the 2018 NPRM doubles the rebound effect from 10% to 20%. It justifies this based on evidence from academic studies, some over a decade old but also more recent studies, many of which present estimates from Europe. The NPRM justification either excludes or dismisses several recent papers on the rebound effect using odometer reading data that find estimates that would point to a lower rebound effect. These papers include West et al. (2017), which shows a 0% rebound effect; Langer et al. (2017), which estimates an 11% value; Knittel and Sandler (2018), which estimates a 14.7% value; and Wenzel and Fujita (2018), which estimates a range of 7.5-15.9%. These ignored recent papers raise questions about the justification for the 20% estimate in the 2018 NPRM. A higher rebound effect both inflates costs (lower benefits due to decreased vehicle miles traveled) and benefits (more crashes are avoided) from a rollback of the standards. The net effect is small, as the NPRM approximately offsets the costs and benefits of the rebound effect.

D. Additional explanation for the difference in costs of compliance with technology between the 2016 TAR and 2018 NPRM

The main text of the paper discusses the reasons why NHTSA's total technology cost savings from the proposed flatlining of the standards compared to the Obama standards are estimated to be much higher in the 2018 NPRM than the technology cost estimates for meeting the Obama standards in the 2016 TAR. These total technology cost differences in meeting the standards are shown in Panel A of Figure 1 in the paper, which shows the costs and benefits of the CAFE standards under NHTSA's analysis.

In both the 2016 and 2018 analyses, we can break down the total cost estimates into average per-vehicle cost differences, and differences in the number of vehicles sold in each model year. Figure S.3 shows average per vehicle cost estimates for the 2016 TAR and the 2018 NPRM.

Figure S.3: Average Technology Cost per Vehicle for the CAFE Standards (2016 U.S. Dollars)



The 2018 per-vehicle cost estimates are more than twice as large as the earlier analysis for many of the model years. The two analyses are difficult to compare, and reasons for this large discrepancy are complex. However, we have been able to uncover the major reasons for these differences. They are:

- The assumptions of what technologies are available and how automakers apply them were changed (e.g., the 2018 analysis had almost no application of Atkinson engines). As a result, the 2018 analysis predicts significantly higher deployment of more-expensive technologies. This is shown in Table S.2, which replicates part of Table VII-6 in the NPRM (Panel A). 24% of vehicles in the 2018 analysis are projected to be strong hybrids by model year 2025. In contrast, Panel B in Figure S.2 shows that only 2.6% of vehicles are strong hybrids by model year 2025 in the 2016 analysis.

- NHTSA did not account for the full extent of flexibilities in how manufacturers can comply with the rules, such as through the use of credit transfers and trading in the 2018 NPRM.[2] In contrast, NHTSA and EPA both accounted for manufacturer use of a least some of these flexible opportunities in the 2016 analysis. In reality, automakers can comply with the regulations by transferring fuel-economy "credits" between their passenger car fleet and their light-duty truck fleet, so that if one fleet over-complies with the regulations, the other can under-comply within some limit (NHTSA limits the amount of trading that can actually occur in this way, but to the extent automobile companies can make these trades, their costs will fall). Credit transferring is also possible across years, so that if an automaker exceeds fuel economy performance in one year, it can meet a less stringent standard in another year. These flexibilities were not included in the 2018 analysis for MY 2021-2025 (although credit transferring was possible from years before 2021), accounting for an important component of why the 2018 costs are higher.
- The 2018 analysis assumes longer time periods are required to redesign many vehicles to meet the standards in a given year, requiring manufacturers to add fuel-saving technologies earlier and incurring the costs for additional years. This is clear from the per-vehicle costs shown in Figure S.3 above. Costs are relatively higher in the early model years under the 2018 analysis (more than five times higher for the 2019 model year) because NHTSA argues that more technology must be added to early model years to meet the 2022-2025 standards.
- The specified costs for electrified vehicles are significantly higher (20-50%) than in the 2016 analysis due to different battery assumptions (e.g., electrode thickness limited to 100 microns), and including additional vehicle electrification components (e.g., liquid cooling systems) recommended by the National Academies (NRC, 2015).
- The two analyses are not comparing standards for the same model years. The 2018 rule analysis compares the Obama standards that increase in successive years until model year 2025, to a standard that stays constant at model year 2020 levels. The 2016 TAR analyses compared a standard that stayed constant at model year 2021 levels to the increasing Obama standards in 2022–2025. The addition of the model year 2021 standard adds substantial costs to the 2018 analysis. See Table S.3 below for further explanation of this point.

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[2] The 2018 notes on page 401: "By statute, NHTSA cannot consider credit flexibilities when setting standards, so most manufacturers (those without a history of civil penalty payment) are assumed to comply with their standard through fuel economy improvements for the model years being considered in this analysis." This restriction leads to an underestimate of compliance costs.

It is important to note that the per vehicle costs shown in Figure S.3 for both the 2016 and the 2018 analyses are overestimates of the true costs because they do not account for other related but separate regulations that will influence the profit maximizing choices of manufacturers. The presence of the ZEV mandate in California and other states in the U.S., and regulations in place now in Europe that require electrification of vehicles in future model years, will have an effect on the cost of producing electric vehicles and of attaining the federal standards.[3]

Panel A: Technology Penetration in the 2018 NPRM

Technology	Standard	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Mild HEVs	Baseline	2.0%	9.0%	14.0%	21.0%	29.0%	32.0%	34.0%	34.0%	32.0%	32.0%	32.0%	32.0%	32.0%
Mild HEVs	Proposal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Strong HEVs	Baseline	3.0%	3.0%	4.0%	7.0%	11.0%	13.0%	16.0%	18.0%	22.0%	24.0%	24.0%	24.0%	24.0%
Strong HEVs	Proposal	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Plug-In HEVs	Baseline	0.0%	0.0%	0.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Plug-In HEVs	Proposal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dedicated EVs	Baseline	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Dedicated EVs	Proposal	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%

Panel B: Technology Penetration in the 2016 TAR for Model Year 2025

Standard	Technology:	Mild HEVs	Strong HEVs	Plug-In HEVs	Dedicated EVs
Reference		3.5%	2.6%	1.7%	2.1%
Control		18.3%	2.6%	1.7%	2.6%

Source for Panel A: Table VII-6 in the 2018 NPRM (p. 600-601). "Baseline" refers to the Obama-era standards. "Proposal" refers to the proposed rollback. Sources for Panel B: Table 12.25 in the 2016 TAR (p. 12-22) for the "reference" case, which freezes standards at model year 2021 levels. Table 12.33 in the 2016 TAR (p. 12-29) is the source for the "control" case, which applies the more stringent Obama-era standards for model years 2022-2025.

Table S.2: Technology Penetration under Baseline and Proposed CAFE Standards (Fleet Average)

The total technology costs across all model years for both analyses can be found by multiplying the per-vehicle costs by NHTSA's sales volume forecast for each model year from 2017-2029. Table S.3 below shows the sales volume forecasts for the 2016 TAR analysis and the 2018 NPRM analysis for the model years being regulated. In the 2016 study, forecasted sales volumes were taken from the Annual Energy Outlook (AEO), and do not change with the stringency of the regulations. The 2018 analysis has baseline sales volumes that are roughly 1.5 million vehicles higher for every model year, consistent with revised AEO forecasts. In addition, the 2018 analysis includes effects of the regulations on vehicle sales. As discussed elsewhere in the paper, sales are higher under the proposed rules that flatline the standards at their 2020 model year levels.

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[3] NHTSA ignored the ZEV mandate in both their 2016 and 2018 analysis of technology compliance costs for the CAFE standards. EPA includes ZEV mandates in their reference case. We focus on comparing costs for the NHTSA analyses between 2016 and 2018, to highlight other cost differences aside from ZEV.

	2016 TAR	2018 NPRM	
Model Year	Sales Volumes	Sales Volumes (Baseline)	Sales Volumes (Proposal)
2021	16.1	17.7	17.7
2022	16.0	17.8	17.8
2023	16.1	17.7	17.8
2024	16.2	17.7	17.8
2025	16.4	17.7	17.9

"Baseline" refers to the Obama-era standards. "Proposal" refers to the proposed rollback that flatlines the standards at model year 2020 levels. Sales volumes are from Table 4.5 (p. 4-10) in the 2016 TAR and from Table VII-5 (p. 598) in the 2018 NPRM.

Table S.3. Forecasts of Sales Volumes by Model Year (Millions of Vehicles)

Assuming a discount rate of 3%, total costs are as shown in Figure 1, Panel A. Converting to 2016 dollars, total costs of meeting the 2022 to 2025 Obama-era standards under the TAR analysis are $90 billion. Total cost savings from holding standards fixed at the 2020 level compared to the Obama standards in the 2018 NPRM are $252.6 billion. Only a small share of this difference can be attributed to the volume difference shown above. Most of it is due to per-vehicle cost differences as we discuss above and in the paper.

As described above, the two analyses are not comparing costs for the same model years. The 2018 cost estimates are higher than the 2016 estimates in part because the 2021 model year standard is included in the 2018 rule. We can understand the magnitude of costs added by this difference by looking at the costs attributed to each model year's standard as reported in the 2018 NPRM. For example, for the proposed 2023 model year standard, what are all of the costs across all model years that must be incurred to meet just that standard? Table S.4 shows these costs for the model years affected by the proposed regulations. This table is taken directly from Table VII-45 on page 652 of the NPRM.

Model Year	2021	2022	2023	2024	2025	Total
Costs	30.5	40.4	51.4	73.9	56.4	252.6

Table shows the costs attributed to meeting the Obama-era CAFE standards for a particular model year, compared to the proposed rollback in which standards are frozen at 2020 levels. Cost are discounted at 3% and presented in billions of 2016 U.S. dollars. Source: Table VII-45 in the 2018 NPRM (p. 652).

Table S.4. Total Technology Costs of the Proposed Change in Standards (Billions of 2016 U.S. Dollars)

Table S.4 shows that the cost savings from freezing the standards at the 2020 model year level are estimated at $30.5 billion. To make the 2016 and 2018 analyses of the cost of attaining the Obama-era standards comparable, this amount should be subtracted from the total costs of the 2018 estimate. This reduces the 2018 costs by about 12% ($30.5/$252.6).

E. Discussion of the inconsistencies in the NPRM's vehicle turnover modeling

As discussed in the main text, the 2018 NPRM argues that the rollback of the affirmed standards to a standard that is frozen at 2020 levels will shrink the overall vehicle fleet by 6 million vehicles in the year 2029, compared to the current standards. This is simply inconsistent with basic economic theory, which predicts that tighter standards make new vehicles more expensive, and fewer will be sold. As a result, used vehicles – which are "produced" from new cars – also become scarcer and thus more expensive. As a consequence, when standards increase vehicle prices, the total fleet size should decrease over time.[4]

Conversely, a rollback should lead to lower prices and increased demand for vehicles, resulting in a larger fleet that will also be newer on average. A rollback of the standard will make both new and used vehicles cheaper. Former non-car owners will enter the market, tempted by the cheaper used vehicles, cheaper new vehicles, or both. We see no case in which this set of price changes would cause someone who formerly owned a car to decide to opt out of the car market altogether. In other words, the fleet size should be expected to increase rather than decrease.

These inconsistencies in the 2018 NRPM arise through integration of a newly developed vehicle scrappage model with NHTSA's VOLPE model. Scrappage does not result as an equilibrium outcome in a model (in contrast to Jacobsen and van Benthem (2015) and Bento et al. (2018)), but instead is modeled exogenously through a linear regression of scrap rates on new vehicle prices, new vehicle fuel costs, vehicle age, lagged values, and some macroeconomic indicators (2018 PRIA, p. 1016). The estimated relationship that results reflect correlations in the data, but when applied to policy simulations there is no economic model present to validate the forecasted change in scrap rates. The six million missing used cars result from this modelling choice.

Second, in relation to the preferred framework, the analysis in the 2018 NPRM does not account for changes in used vehicle prices that result from interactions between new and used car markets as a result of the standard. Basic economic theory predicts that the rollback, by reducing new vehicle prices, will lower prices of and demand for used vehicles. Lower used vehicle prices have a direct impact on scrappage rates as the owners of older vehicles face decisions between repairing their cars and scrapping them. The 2018 PRIA scrappage model bypasses this mechanism altogether, looking only at a reduced-form relationship. As a result, there is nothing in the model that enforces economic principles, allowing misleading conclusions related to the overall size of the fleet and fleet composition. The approach taken undermines EPA and NTHSA modeling efforts to improve the understanding of the role of scrappage in relation to costs and benefits of fuel economy standards.

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[4] How much smaller the fleet will be depends on the magnitude of the price changes and the aggregate elasticity to the outside good. In cities with well-developed public transit, for example, the fleet should shrink more than it would in rural areas where there may be limited outside options.

F. Explanation of main benefit-cost tables in the 2018 *Notice of Proposed Rulemaking*

To understand and compare the benefit-cost tables of the two rules, it is useful to first cover the recent institutional background. The Energy Independence and Security Act of 2007 mandated an increase of fleet-wide fuel economy to a minimum of 35 miles per gallon by model year (MY) 2020. Under the Obama Administration in 2012, EPA and NHTSA promulgated a rule that sped up the timeline and led to an increase in fleet-wide fuel economy to reach 35 miles per gallon by 2016. Further, a timeline of future standards was laid out to reach roughly 55 miles per gallon (EPA compliance MPG ratings, not on-road ratings) by MY 2025. The steepest increase in the standards occurred from 2022 to 2025. To assess the feasibility of these MY 2022-2025 standards, there was a "midterm evaluation" or "midterm review" built into the rule that required a reassessment by April 1, 2018. This was in part necessitated by the statutory requirement that NHSTA can only set CAFE standards for a limited number of years into the future (EPA faced no such requirement).

In 2016, EPA and NHTSA jointly issued a Draft Technical Assessment Report (TAR) that contained a benefit-cost analysis that supported the previous timeline of MY 2022-2025 standards. The regulatory analysis in the TAR examined the benefits and costs of these standards relative to holding the standards constant at MY 2021 levels. In January 2017, the outgoing Obama Administration EPA affirmed the so-called "augural" MY 2022-2025 standards, so without another rulemaking, those standards were legally binding. However, NHTSA was required by statute to conduct another rulemaking for the MY 2022-2025 standards.

In 2018, the Trump Administration EPA and NHTSA jointly published the Notice of Proposed Rulemaking (NPRM) that proposes freezing the standards at MY 2020 levels through MY 2026. This is commonly called the "rollback" of the standards. The regulatory analysis in the NPRM and accompanying proposed regulatory impact analysis (PRIA) document performs a benefit-cost analysis of the newly proposed standards held fixed at MY 2020 levels for MY 2021-2025 (MY 2026 was not included in the analysis). The regulatory analysis compared these standards to seven different alternatives of steadily increasing standards. The most stringent of these alternatives are the augural standards, which included the MY 2021 standards that had been promulgated by EPA in 2012, as well as the MY 2022-2025 augural standards that had been affirmed by EPA in January 2017.

The tables that follow present the benefit-cost analysis of the proposed rollback of the augural standards that were affirmed in January 2017. They present the costs and benefits—as calculated by the agencies—of a policy that freezes the standards at 2020 levels until 2025, relative to keeping the more ambitious 2021-2025 augural standards. In what follows, we refer to this comparison as the benefit-cost analysis of the rollback. Note that there is one additional model year (MY 2021) included in the rollback analysis.

We first replicate the main benefit-cost tables for the rollback of both the CAFE standards and the GHG standards, exactly as they appear in the NPRM. Table S.5 replicates Table II-25 (p. 170-171); Table S.6 replicates Table II-27 (p. 172-173). We then provide a brief explanation of the table entries, and discuss how these numbers might change once the inconsistency in fleet size and total VMT has been corrected.

Line	**Affected Party**	**Source**	**Private Benefits and (Costs)**	**Billion 2016$**
1	Vehicle Manufacturers	CAFE model	Savings in technology costs to increase fuel economy	$252.6
2			Reduced fine payments for noncompliance	$3.0
3		assumed = -(1+2)	Net loss in revenue from lower vehicle prices	($255.6)
4		net = 1+2+3	Net benefits to manufacturers	$0.0
5	New Vehicle Buyers	assumed = 3	Lower purchase prices for new vehicles	$255.6
6		CAFE model	Reduced injuries and fatalities from higher vehicle weight	$2.4
7			Higher fuel costs from lower fuel economy (at retail prices)*	($152.6)
8			Inconvenience from more frequent refueling	($8.5)
9			Lost mobility benefits from reduced driving	($61.0)
10	net = 5+6+7+8+9		Net benefits to new vehicle buyers	$35.9
11	Used Vehicle Owners	CAFE model	Reduced costs for injuries and property damage costs from driving in used vehicles	$88.3
12	All Private Parties	net = 4+10+11	Net private benefits	$124.2
Line	**Affected Party**	**Source**	**External Benefits and (Costs)**	**Billion 2016$**
13	Rest of U.S. Economy	CAFE model	Increase in climate damages from added GHG emissions**	($4.3)
14			Increase in health damages from added emissions of air pollutants**	($1.2)
15			Increase in economic externalities from added petroleum use**	($10.9)
16			Reduction in civil penalty revenue	($3.0)
17			Reduction in external costs from lower vehicle use***	$51.9
18			Increase in Fuel Tax Revenues	$19.7
19	net = 13+14+15+16+17+18		Net external benefits	$52.1
Line	**Affected Party**	**Source**	**Economy-Wide Benefits and (Costs)**	**Billion 2016$**
20	Entire U.S. Economy	total = 1+2+5+6+11+17+18	Total benefits	$673.50
21		total = 3+7+8+9+13+14+15+16	Total costs	($497.2)
22		net = 20+21 (also =12+19)	Net Benefits	$176.3

*Value represents lost fuel savings from lowered fuel economy of MY's 2017-2029 and gained fuel savings from more quickly replacing MY's 1977 to 2029 with newer vehicles.

**Value represents lost external benefits from lowered fuel economy of MY's 2017-2029 and lowered external costs from more quickly replacing MY's 1977 to 2029 with newer vehicles.

*** Value includes lower external costs from reducing rebound effect and any change in overall fleet usage from more quickly replacing MY's 1977 to 2029 with newer vehicles.

Table S.5: Benefits and Costs Resulting from the Proposed Rollback of the CAFE Standards (Present Values Discounted at 3%)

Line	Affected Party	Source	Private Benefits and (Costs)	Billion 2016$
1	Vehicle Manufacturers	CAFE model	Savings in technology costs to increase fuel economy	$259.8
2			Reduced fine payments for noncompliance	$0.0
3		assumed = -(1+2)	Net loss in revenue from lower vehicle prices	($259.8)
4		net = 1+2+3	Net benefits to manufacturers	$0.0
5	New Vehicle Buyers	assumed = 3	Lower purchase prices for new vehicles	$259.8
6		CAFE model	Reduced injuries and fatalities from higher vehicle weight	$7.5
7			Higher fuel costs from lower fuel economy (at retail prices)*	($165.2)
8			Inconvenience from more frequent refueling	($9.4)
9			Lost mobility benefits from reduced driving	($69.5)
10	net = 5+6+7+8+9		Net benefits to new vehicle buyers	$23.2
11	Used Vehicle Owners	CAFE model	Reduced costs for injuries and property damage costs from driving in used vehicles	$111.0
12	All Private Parties	net = 4+10+11	Net private benefits	$134.2

Line	Affected Party	Source	External Benefits and (Costs)	Billion 2016$
13	Rest of U.S. Economy	CAFE model	Increase in climate damages from added GHG emissions**	($4.7)
14			Increase in health damages from added emissions of air pollutants**	($0.8)
15			Increase in economic externalities from added petroleum use**	($11.9)
16			Reduction in civil penalty revenue	$0.0
17			Reduction in external costs from lower vehicle use***	$62.4
18			Increase in Fuel Tax Revenues	$21.5
19	net = 13+14+15+16+17+18		Net external benefits	$66.5

Line	Affected Party	Source	Economy-Wide Benefits and (Costs)	Billion 2016$
20	Entire U.S. Economy	total = 1+2+5+6+11+17+18	Total benefits	$722.00
21		total = 3+7+8+9+13+14+15+16	Total costs	($521.3)
22		net = 20+21 (also =12+19)	Net Benefits	$200.7

*Value represents lost fuel savings from lowered fuel economy of MY's 2017-2029 and gained fuel savings from more quickly replacing MY's 1977 to 2029 with newer vehicles.

**Value represents lost external benefits from lowered fuel economy of MY's 2017-2029 and lowered external costs from more quickly replacing MY's 1977 to 2029 with newer vehicles.

*** Value includes lower external costs from reducing rebound effect and any change in overall fleet usage from more quickly replacing MY's 1977 to 2029 with newer vehicles.

Table S.6: Benefits and Costs Resulting from the Proposed Rollback of the GHG Standards (Present Values Discounted at 3%)

Explanation of Tables S.5 and S.6:

- Lines 1-4: Manufacturers save substantially on technology costs (line 1) and pay fewer non-compliance fines (line 2), but are assumed to pass through all these cost savings to consumers (line 3), for a combined net benefit of zero for automobile manufacturers.

- Lines 5-10: New vehicle buyers pay lower prices (line 5), face slightly lower accident risk in their now-heavier vehicles (line 6), pay substantially higher fuel costs (line 7), face a time cost of more frequent refueling due to the lower fuel economy of their vehicles (line 8), and drive less and therefore enjoy fewer mobility benefits (line 9).
- Used vehicle owners see reduced costs of (fatal) injuries and property damage (line 11).
- The various costs and benefits to new and used vehicle owners combine to produce a substantial net private benefit (line 12).
- Lines 13-19: The increase in gasoline consumption under the proposed rollback translates into higher climate damages (line 13), higher health damages from local tailpipe emissions (line 14), higher external costs of energy security (line 15), lower government revenues from collecting CAFE fines (line 16; this offsets line 3), substantially lower external costs from congestion and noise (line 17), and higher gasoline tax revenues (line 18; this partially offsets line 7). These combine in an estimate of net external benefits (line 19).
- Adding up the various benefits (line 20) and costs (line 21) yields the final net benefits of the proposed rollback of the standards (line 22).

As discussed in the main text, correcting the flaws in the fleet size and VMT resulting from NHTSA's fleet turnover model reported in the NPRM will have substantial impacts on several important entries in Tables S.5 and S.6.

- Fuel costs (line 7) and time costs of refueling (line 8) will increase even more, but these effects will likely be offset by an increase in driving benefits (line 9); the impact on net benefits will be small.
- The large projected gain from reduced fatalities and property damages among used vehicle owners ($88.3 billion under the CAFE standards, $110 billion under the GHG standards; line 11) should likely fall below zero. The reported large positive benefits are largely driven by a projected 2.4% reduction in fleet-wide VMT by the year 2029 under the CAFE standards, which is attributable to avoided rebound and a 1.9% reduction in the overall fleet size (and corresponds to 6 million fewer vehicles (PRIA Table 11-29, p. 1424). Under the GHG standards, the reduction in VMT and fleet size are 2.9% and 2.1%, respectively (PRIA Table 11-30, p. 1425). We argue in the main text that this is inconsistent with economic theory and that fleet size (and the VMT associated with fleet size) should *increase* following a rollback. There are two important caveats we should note. First, VMT associated with the rebound effect (the effect of higher gasoline cost per mile) would still decrease. We note that much of the change in PRIA Table 11-29 appears attributable to fleet size, though a further breakdown on VMT changes is needed. Furthermore, the cost associated with crashes, injuries, and fatalities in line 11 of Tables S.5 and S.6 above appears entirely related to fleet size (changes in safety associated with the rebound effect are netted out in the cost calculation in Table VII-45 of the NPRM, leaving only fleet-size-related changes). Second, the composition of vehicles within the used fleet is

likely to change; we have commented so far only on the aggregate price and desirability of used cars. The total number of certain models (for example hybrid models) on the road is likely to decrease with the rollback, while the numbers will grow for other models.[5]

- Adding back the 6 million missing vehicles will also increase the external costs of the rollback of the Obama-era standards. The resulting higher gasoline consumption will lead to larger climate damages (line 13), health damages (line 14), and geopolitical externalities from increased dependence on foreign oil (line 15).
- The resulting higher VMT will reduce the benefits from noise and congestion (line 17): indeed, the rollback could even worsen noise and congestion to the extent fleet size increases. There is a countervailing force in the benefit-cost analysis, however, appearing in line 9: changes in line 17 are mostly netted out against mobility benefits appearing in line 9, leaving the impact on total net benefits modest.

We report in the main text that the net benefits from the rollback change substantially when we correct the benefit-cost analysis in two ways. First, we (conservatively) set the fleet-size induced change in crashes (line 11 in Tables S.5/S.6) to zero. Second, we value greenhouse gas emissions at the global rather than the domestic social cost of carbon. Specifically, rather than using the NPRM's $7.48 per ton of CO_2 (in 2016 U.S. dollars; 2018 PRIA, p. 1109), we follow the TAR's global cost of carbon of $48.42 (in 2016 U.S. dollars; 2016 TAR, p.990). For the CAFE standards, the fleet size adjustment ($88.3 billion) and the upward correction in the social cost of carbon ($23.5 billion) combine to `missing benefits' of $111.8 billion. For the GHG standards, these numbers amount to a fleet size adjustment of $111.0 billion and a social cost of carbon correction of $25.7 billion, for a total of $136.7 billion.

This correction alone reduces the net benefits of the rollback of the CAFE standards by 63.4% (68.1% for the GHG standards). On top of that, only a very minor reduction in the assumed technology costs would flip the sign of the net benefits and thus change the conclusion that a rollback has positive net benefits. If the technology costs of complying with the CAFE standards – which are 2.8 to 7.5 times higher in the 2018 NPRM than in the 2016 TAR – are only 26% lower, the rollback is no longer justified. For the GHG standards, the reduction would have to be 28%. Even with these reductions, technology costs would still be 2.1 and 5.7 times higher than in the 2016 TAR for the CAFE and GHG standards, respectively.

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[5] Note that this type of change in fleet composition plays a minor role in the NPRM. The number of fatalities by 2029 drops by 2.5% for the CAFE standards (2018 PRIA Table 11-29, p. 1424) and by 3.1% for the GHG standards (2018 PRIA Table 11-30, p. 1425). Fatalities decrease almost proportionately with VMT under both standards. This suggests that composition effects in NHTSA's model are small. The overall fleet size effect of a rollback (under which the aggregate price index of vehicles decreases relative to the price of other goods) is theoretically harder to demonstrate in the presence of many vehicle models. Consumer heterogeneity (e.g., in the price elasticities of vehicle demand across consumers) complicates the modeling even further although, again, we have little reason to believe this is a first-order issue. A more sophisticated modeling exercise that includes individual vehicle models would be required to judge the size and direction of any compositional effect.

G. Data for Figure 1

Table S.7 below provides the data used to construct Figure 1. To enable a direct comparison with Tables 12.82 and 13.25 in the 2016 TAR, Table S.7 draws on numbers from Tables VII-45 and VII-51 in the 2018 NPRM. The resulting overall net benefits reported in these tables are consistent with those reported in Tables II-25 and II-27 (replicated in Tables S.5 and S.6 above), but the costs and benefits are broken down in slightly different categories.

Note that table S.7 (and Figure 1 in the main article) present the cost and benefits of the affirmed standards relative to a baseline in which standards are frozen at 2021 levels (2016 TAR) or 2020 levels (2018 NPRM). To interpret impacts of a *rollback* of the standard, one should change the signs of all costs and benefits.

Line	Benefits and (Costs)	CAFE standards		GHG standards	
		2016 TAR Billion 2016$	*2018 NPRM*	*2016 TAR Billion 2016$*	*2018 NPRM*
		(1)	(2)	(3)	(4)
1	Vehicle Technology Costs	($90.7)	($252.6)	($34.6)	($259.8)
2	Noise and Congestion	($4.3)	($51.9)	($6.0)	($62.5)
3	Rebound Crash Costs	($1.8)	($106.8)	($2.6)	($122.5)
4	Non-Rebound Crash Costs	$0.0	($90.7)	$0.0	($118.6)
5	Maintenance	($5.2)	$0.0	($1.6)	$0.0
6	Pre-Tax Fuel Savings	$125.7	$132.9	$91.5	$143.8
7	Energy Security	$9.3	$10.9	$4.8	$11.9
8	CO2 Damages Avoided	$27.8	$4.3	$19.2	$4.7
9	Non-GHG Damages Avoided	$11.3	$1.2	$9.1	$0.8
10	Refueling Benefits	$6.2	$8.5	$7.3	$9.4
11	Rebound Benefits	$9.3	$167.9	$10.1	$192.1

Sources for CAFE standards: 2016 TAR, Table 13.25, p. 1215; 2018 NPRM, Table VII-45, p. 652.
Sources for GHG standards: 2016 TAR, Table 12.82, p. 1089; 2018 NPRM, Table VII-51, p. 656.
Costs and benefits from the TAR are in 2013$ and are converted to 2016$ with a 1.0303 conversion factor.
See page 1000 in the 2016 TAR for a breakdown between rebound crash costs and noise & congestion costs.

Table S.7: Data for the Comparison between the 2016 TAR and the 2018 NPRM, for the CAFE Standards and the GHG Standards (Present Values Discounted at 3%)

Explanation of Table S.7:

- Columns 1 and 3 show the costs and benefits for the CAFE and GHG standards from the 2016 TAR; columns 2 and 4 show the corresponding costs and benefits from the 2018 NPRM. The correspondence between Tables S.5/S.6 and Table S.7 is as follows:[6]

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[6] Note that all signs are flipped because Table S.7 quantifies the effect of adopting the affirmed Obama-era standards, while Tables S.5 and S.6 consider a rollback of those standards that freezes the policy at 2020 levels.

    - Lines 1, 2, 7, 8, 9, and 10 in Table S.7 are identical to lines 1, 17, 15, 13, 14, and 8 in Tables S.5/S.6.
    - Line 3 in Table S.7 is equal to the sum of lines 6 and 11 in Tables S.5/S.6.
    - The sum of lines 4 and 11 in Table S.7 is equal to line 9 in Tables S.5/S.6.
    - Line 5 in Table S.7 is not quantified in the 2018 NPRM tables and is therefore set equal to zero.
    - Line 6 in Table S.7 is equal to the sum of lines 7 and 18 in Tables S.5/S.6.
- Note that Table S.7 breaks down crash costs from rebound (line 3) and non-rebound (line 4); the latter represents the accident costs from fleet size and composition effects.

H. Additional references

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