Sensitivity and Uncertainty Analysis

With a view toward meeting OMB guidance regarding rulemaking analysis, DOT's analyses supporting CAFE standards have, since 2002, included formal sensitivity and uncertainty analysis. DOT's sensitivity analysis involves evaluating how key results (e.g., costs, benefits) change if discrete key input assumptions and estimates (e.g., fuel prices) change. DOT's uncertainty analysis involves estimating the probabilities of different outcomes (e.g., different net benefits to society), based on the estimated probabilities of a range of different input assumptions and estimates.

Sensitivity Analysis

For the 2012 rulemaking regarding post-2016 standards, DOT's sensitivity analysis examined (separate) side cases involving different estimates and assumptions for:

- fuel prices
- rebound effect
- value of avoiding CO2 emissions
- valuation of CH4 and N2O (non - zero)
- military security benefits (non - zero)
- consumer benefits (less than 100% of theoretical)
- battery cost
- mass reduction cost
- potential for market - driven fuel economy increases (beyond required by CAFE)
- exclusion of shift optimizer

The Final RIA, Chapter X (pp. 1084 - 1121) features the definitions and results associated with each sensitivity case, but the table below summarizes the impact on net benefits of each alternative input assumption.

Sensitivity Case	Net Benefits ($B)	% change from Central
High Fuel Price	628.6	34
Low Fuel Price	299.6	– 36.1
5% Rebound Effect	489.6	4.4
15% Rebound Effect	466.2	– 0.6
20% Rebound Effect	454.5	– 3.1
$0.12/gal Military Security Premium	493.2	5.2
$5/ton CO2	440.6	– 6.0

$36/ton CO2	507.2	8.2
$68/ton CO2	580.6	23.8
High GWP gases included in CO2e emissions	478.1	2
50% Consumer benefit	233.1	– 50.3
75% Consumer benefit	355.5	– 24.2
Post-Warranty repair costs	459.6	– 2.0
Low battery cost	478.1	2
High battery cost	477.4	1.8
Low cost mass reduction	483.9	3.2
High cost mass reduction	474	1.1
Market-driven baseline	320.7	– 31.6
No shift optimization	455	– 3.0

Most of the alternative input assumptions considered in the sensitivity cases produce small changes to total program net benefits. However, several of them have significant impacts. In particular, fuel prices, the social cost of carbon emissions, the percentage of consumer benefits that can be attributed to the standards, and the behavior of the market in the absence of CAFE increases after MY 2016 all have the potential to alter total net benefits by more than 25 percent. The factors with the largest impact are also among the least certain inputs.

Fuel price forecasts are notoriously inaccurate, and the forecasts used in this analysis (from the AEO 2012 Early Release) really only capture the long-term trend, rather than any annual or inter-annual variability. Estimates of the social cost of carbon emissions vary widely in the literature, and large deviations from the nominal value in the Final Rule ($22 in 2010, increasing annually thereafter) have the ability to significantly increase the benefits of the rule. In the case where manufacturers assume new vehicle buyers place some small value on fuel economy (the equivalent of willingness to pay for fuel economy technology increases with one-year payback periods) in excess of the levels required by CAFE, total program net benefits are reduced by over 30 percent.

In addition to the sensitivity cases listed above, the agency also analyzed the impact that having a retail price equivalent (RPE) factor of 1.5 for all technologies would have on the various alternatives instead of using the indirect cost markup (ICM) methodology. The ICM methodology results in an overall markup factor of 1.2 to 1.25 compared to the RPE markup factor from variable cost of 1.5. Next, the agency conducted a separate sensitivity analysis using values that were derived from the 2011 NAS report. This

analysis used an RPE markup factor of 1.5 for non-electrification technologies, which is consistent with the NAS estimation for technologies manufactured by suppliers, and a RPE markup factor of 1.33 for electrification technologies (HEV, PHEV and EV); three types of learning which include no learning for mature technologies, 1.25 percent annual learning for evolutionary technologies, and 2.5 percent annual learning for revolutionary technologies; technology cost estimates for 52 percent (33 out of 63) technologies; and technology effectiveness estimates for 56 percent (35 out of 63) of technologies. The results are summarized in the table below.

Cost Method and Set of Cost Estimates	MY 2025 Achieved MPG	Average MY 2025 Per-Vehicle Technology Cost	MY 2017-2025 Net Benefits ($billion), 3% DR
Passenger Cars			
ICM w/Main Analysis Costs	54.07	$1,578	293.1
RPE w/Main Analysis Costs	53.92	$1,943	273.3
ICM w/ NAS Costs	52.78	$2,103	242.9
Light Trucks			
ICM w/Main Analysis Costs	39.29	$1,226	175.8
RPE w/Main Analysis Costs	39.14	$1,491	181.2
ICM w/ NAS Costs	37.71	$1,375	154.6

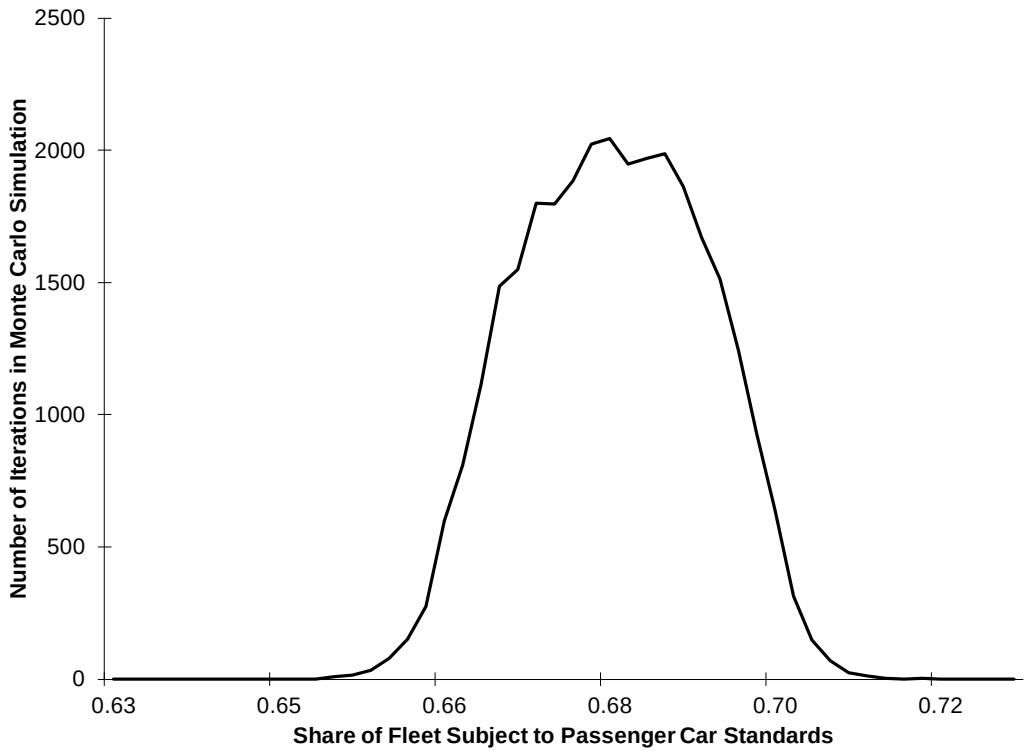
However, the sensitivity analysis cases still offer a somewhat limited perspective of the true uncertainty surrounding the estimated net benefits in the central analysis of the Final Rule. In each case, assuming that only a single parameter deviates from the nominal values in the central analysis holds all others at those levels, and obscures some of the more complicated interactions among model inputs and decision logic.

Uncertainty Analysis

OMB Circular A-4 directs agencies to conduct formal probabilistic uncertainty analysis of complex rules where there are large, multiple uncertainties whose analysis raises technical challenges or where effects cascade and where the impacts of the rule exceed $1 billion. For the 2012 rulemaking regarding post-2016 standards, DOT's uncertainty analysis varied all of the following simultaneously, using probability distributions for each:

- technology costs
- technology effectiveness
- fuel prices
- potential for market - driven fuel economy increases (beyond required by CAFE)
- average vehicle miles traveled per vehicle (differentiated by passenger cars and light trucks)
- rebound effect
- value of oil consumption externalities

In addition to these factors, the uncertainty analysis contains the only consideration of uncertainty in the new vehicle market. Since the total new vehicle sales for every model year and the passenger car share of the new vehicle market are both derived using outputs from EIA's NEMS model, and then used to modify the purchased market forecast, we estimated the difference equation in NEMS that determines passenger car share and integrated it into the CAFE model for the Monte Carlo simulations. As vehicles attributes (PC weight, fuel economy, power, etc.) and fuel prices change within each draw, the share of passenger cars in the new vehicle market responds to those changes and progresses from its historical starting point in 2010. The graph below shows the variation in the passenger car share in MY 2025resulting from the inclusion of this relationship.



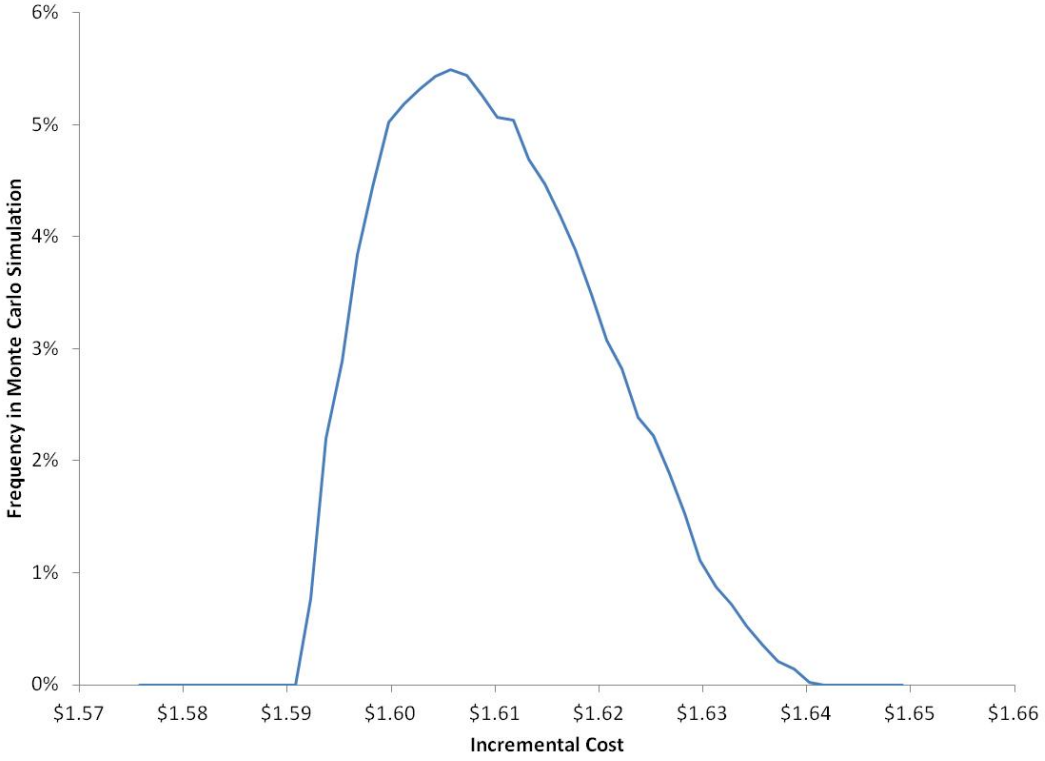
The Final RIA, Chapter XII (pp. 1122 - 1173) contains the detailed discussion of the uncertainty analysis for the Final Rule, including the probability distributions associated with each uncertainty and the results of the simulations.

The agency modeled the plausible range of costs individually for each technology using beta distributions with mode values equal to the corresponding technology costs used in the central analysis. The beta distribution was chosen to represent the higher probability implicit in the central values, but also recognizing that alternative values recommended by the National Academy of Sciences (NAS) would have some probability of occurring. The agency calculated the ratio of total MY 2025 costs under the central values used in this analysis and compared them to the alternate values based on NAS recommendations, and found that NAS recommended values were 1.45 times the central values. The agency created a beta model based on a mode equal to the central value, with the tails defined based on the average confidence intervals found in the NAS study. This confidence interval (18.6%) was added to the NAS relative cost.

There were no confidence intervals provided in the FEV reports, which defines the mode value, so the lower tail was defined as the absolute value of the difference between the NAS value and its upper confidence interval subtracted from the central values.

This effectively assigned a confidence interval to the central values of 27%. Within these parameters, the agency chose alpha and beta values of 1.8 and 3.14, respectively, to assign a 5% probability that values chosen would be equal to or greater than the NAS costs.

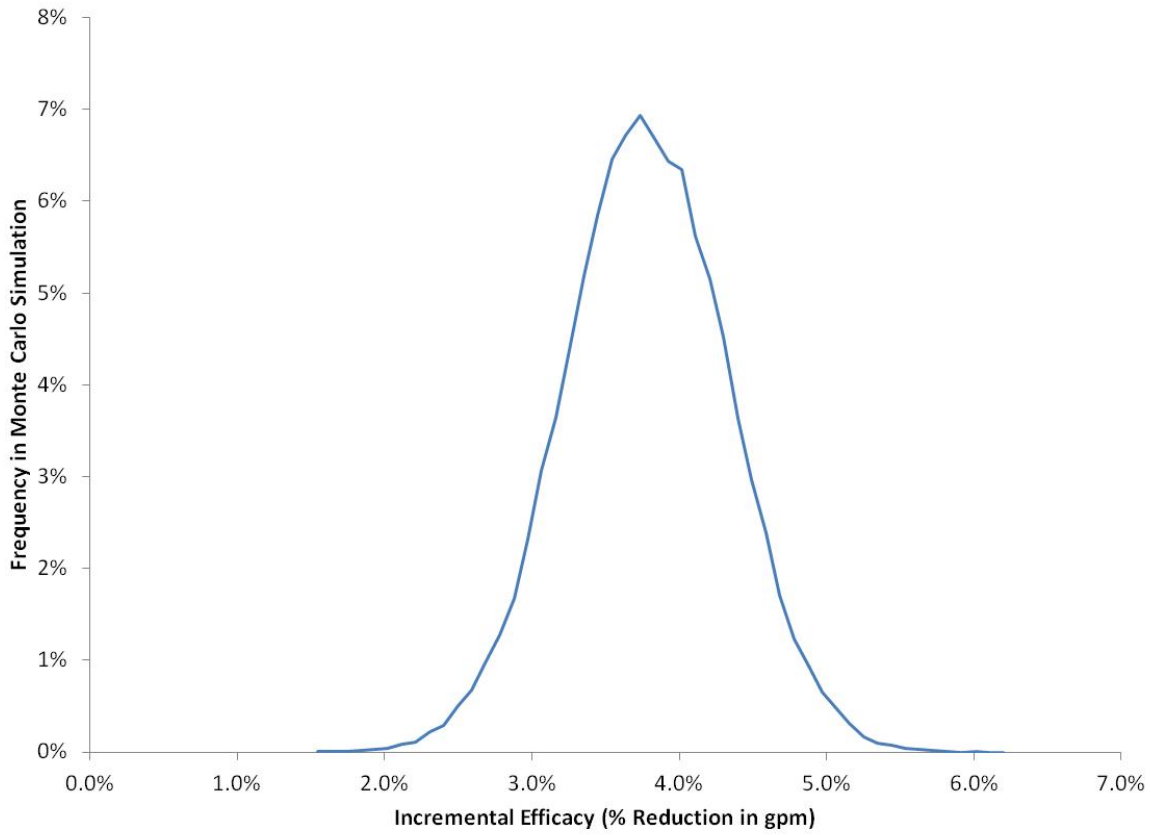
Sample of Technology Incremental Cost "Draw" Distribution for Shift Optimizer



The agency used what were deemed the most likely effectiveness values in the main analysis. For the uncertainty analysis, the central NPRM value and the NAS-recommended value for effectiveness were used in establishing a range for variation. In many cases, the values were the same. In this case, a normal distribution was used and, as had been done in previous uncertainty analysis for CAFE rule-making, technology complexity was used to determine the standard deviation for the distribution. The determination of complexity was by agency expert professional judgment, and divided into low-complexity, medium-complexity and high-complexity.

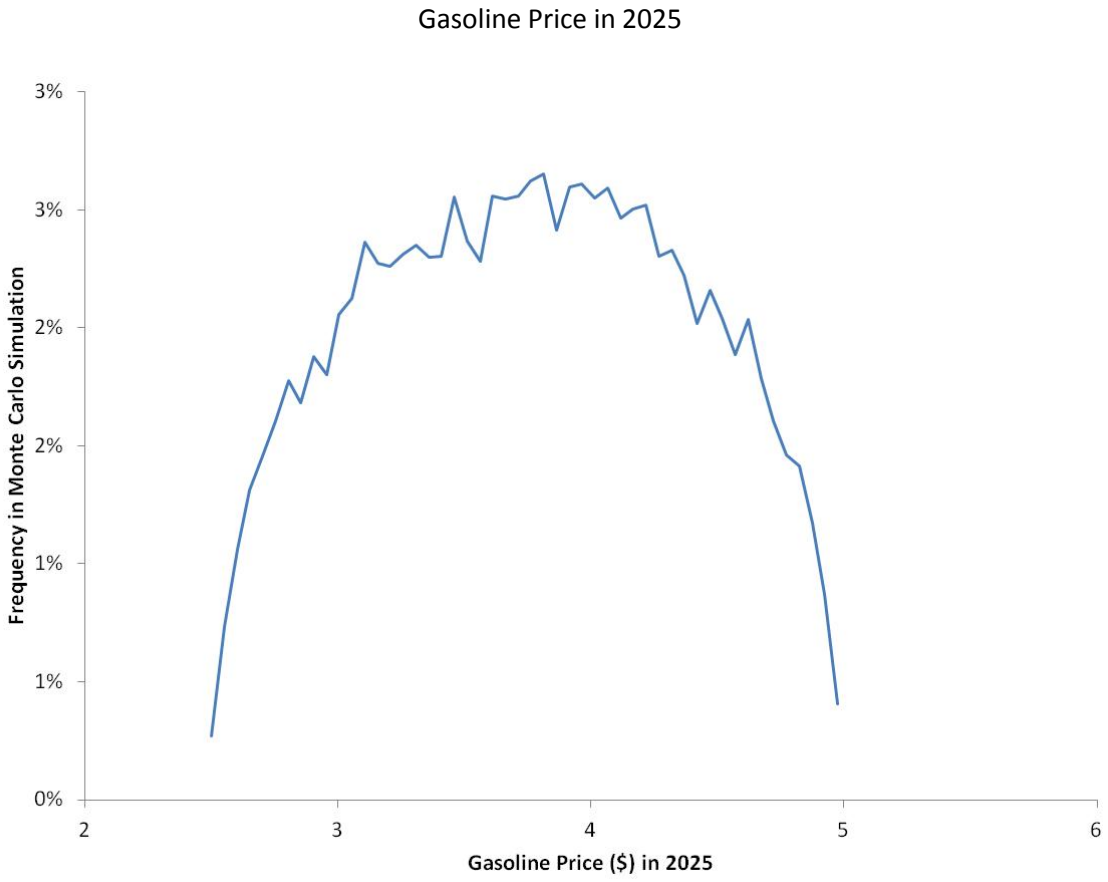
In cases where the NAS value did not equal the central NPRM value, a beta distribution was used to give a distribution which had 20% probability of being outside of the range between the NAS value and the central NPRM value. The beta parameters used were 1.2 and 1.055 for cases where the NAS value was less than the central NPRM value, and 1.1 and 1.411 for cases where the central NPRM value was less than the NAS value. A full accounting of complexity designation for each of the 65 technologies can be found on pages 1126-1128 of the FRIA. An example of a technology effectiveness distribution is shown below.

Sample of Technology Incremental Efficacy "Draw" Distribution

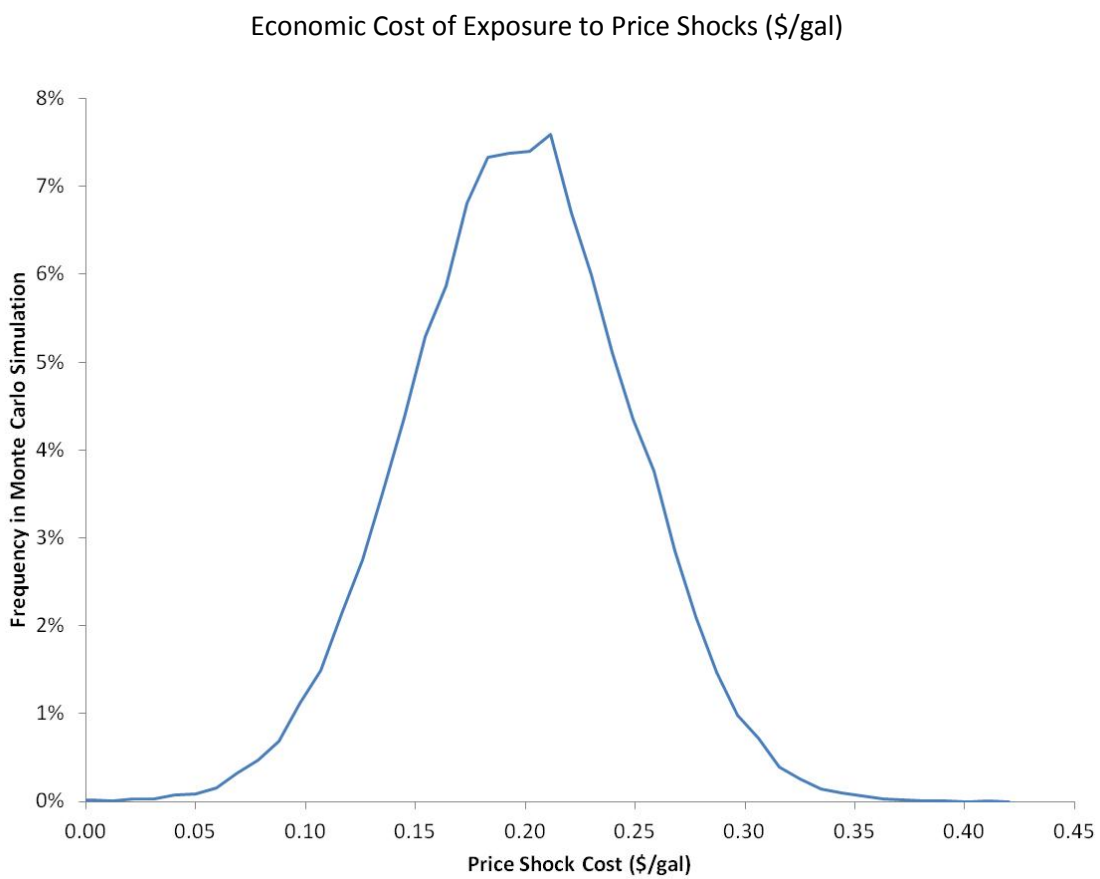


Perhaps the most influential uncertainty in the analysis, fuel prices, was treated in a more continuous fashion than has been the case in previous rulemakings, which simply assigned a probability of .5 to the EIA's reference case oil projection and a probability of .25 to each of the low and high projections. The analysis still relies on the price projections from the AEO, in this case the AEO 2012 Early Release. From these forecast fuel prices, a set of distributions were made for each year (up to 2100) for each fuel type (gasoline, diesel, ethanol-85, electricity). The Reference case, LOP and HOP were, for each fuel, fit to a curve to supply a less jagged target (this reduced the annual variation in the projections, but preserved the long-term trend which was most relevant to this analysis), and a beta distribution was fit to each year for each fuel. This distribution used the curve-fitted Reference case as the mode and was calibrated to give approximately 12.5% probability that the chosen fuel price would be lower than LOP or higher

than HOP. From here, a single random value is chosen to represent the percentile of each (annual) beta distribution, tracing out a full time series of fuel prices for each random draw. The graph below shows the resulting distribution of gasoline prices in 2025 (in constant $2010).

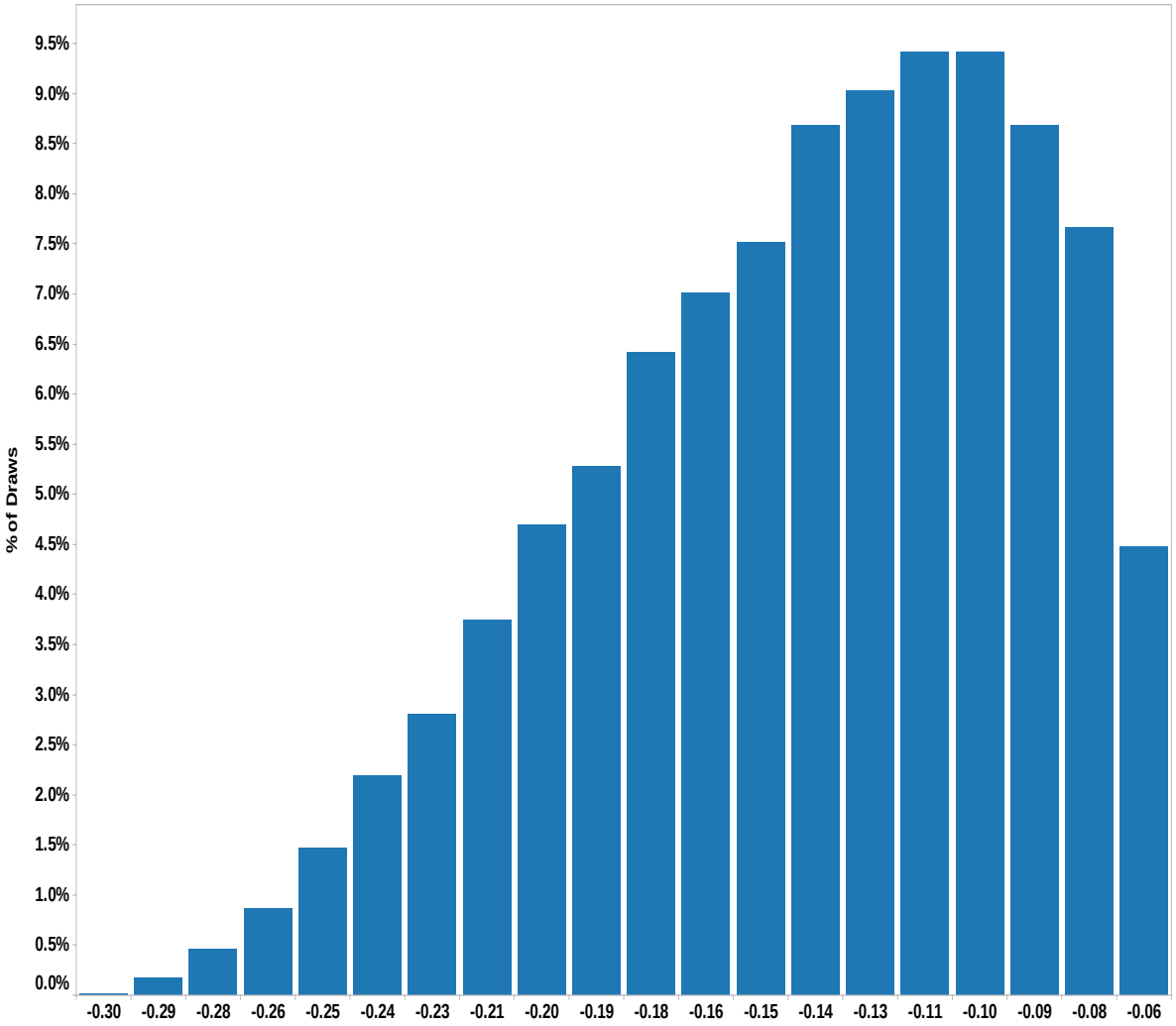


It is estimated that each gallon of fuel saved that results in a reduction in U.S. petroleum imports (either crude petroleum or refined fuel) will reduce the expected costs of oil supply disruptions to the U.S. economy by $0.097 to $0.297, with the actual value most likely to be $0.197 per gallon. The uncertainty analysis draws samples from a normal distribution with a mean of $0.197 and a standard deviation of $0.05, developed so that the upper and lower bounds of the estimated range occur two standard deviations from the mean.



For the treatment of the rebound effect in the uncertainty analysis, a range of 5 to 30 percent was used and employed in a slightly skewed beta distribution which produced a mean of approximately 14.2 percent. The skewed distribution reflects the agency's belief that the more credible studies that differ from the 10 percent value chosen for the main analysis fall below this value (*i.e.*, are more negative) and differ by more substantial margins than the upper range of credible values.

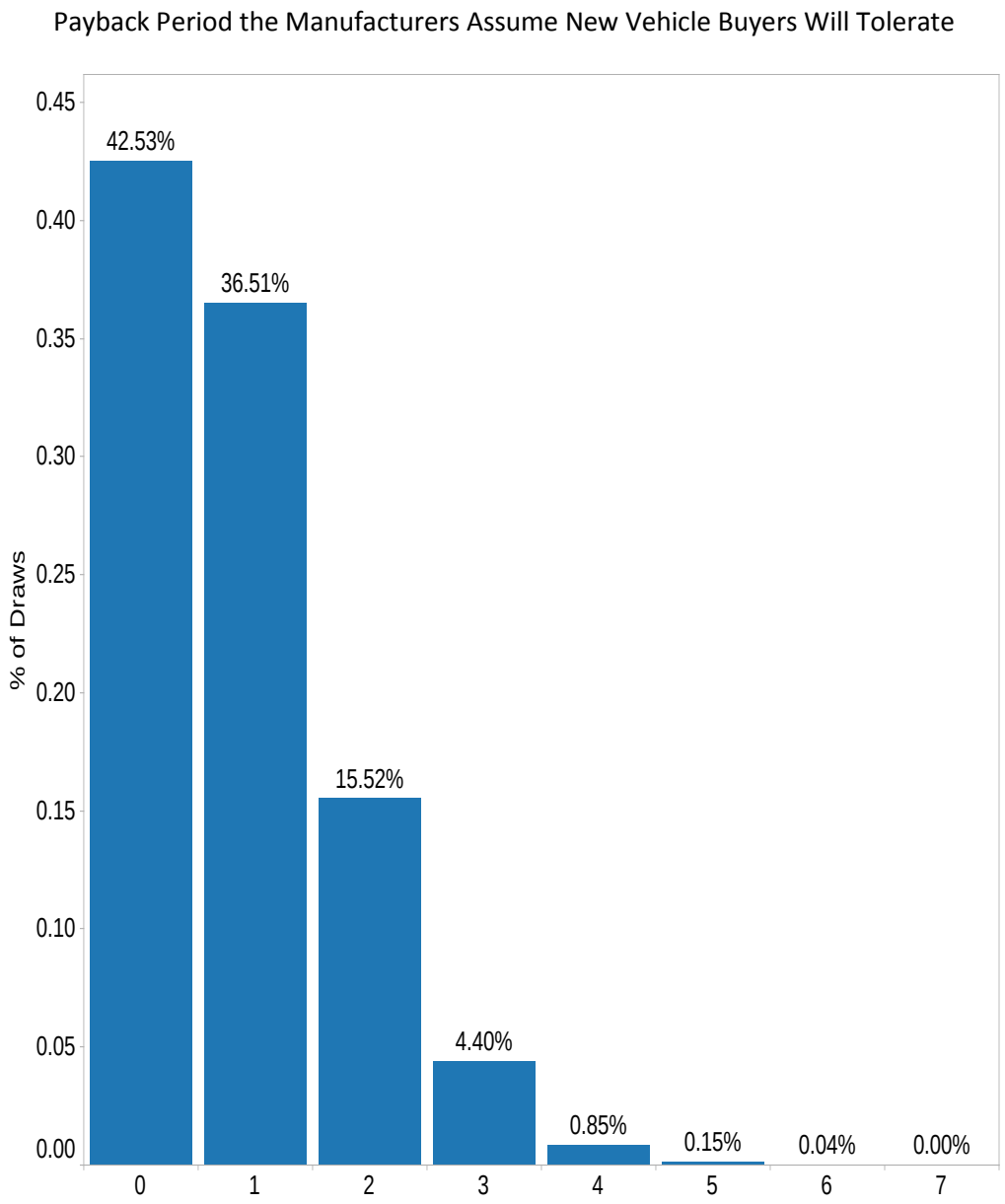
Rebound Effect Distribution



The CAFE model implicitly includes the capability to apply appropriate amounts of technology under varying fuel price cases by including a variable that represents manufacturers' assumption about consumer willingness-to-pay for fuel economy technology. This willingness-to-pay is characterized as the payback period for fuel economy technology investments, meaning the number of years' worth of fuel savings necessary to balance the cost of the new technology. In the central analysis, the model alters that variable to be zero once a manufacturer reaches compliance (or decides to pay fines, if they have historically done so). This means that no additional technology is added beyond the standards in the baseline, or in any of the other regulatory scenarios.

Assuming some non-zero payback period ensures that when fuel prices are very high, manufacturers will continue to add cost-effective fuel economy technologies even when the standards are not sufficient to force these additions. As one might expect, higher fuel prices and longer payback periods result in more fuel economy technology being added beyond the level mandated by the standards, while lower fuel

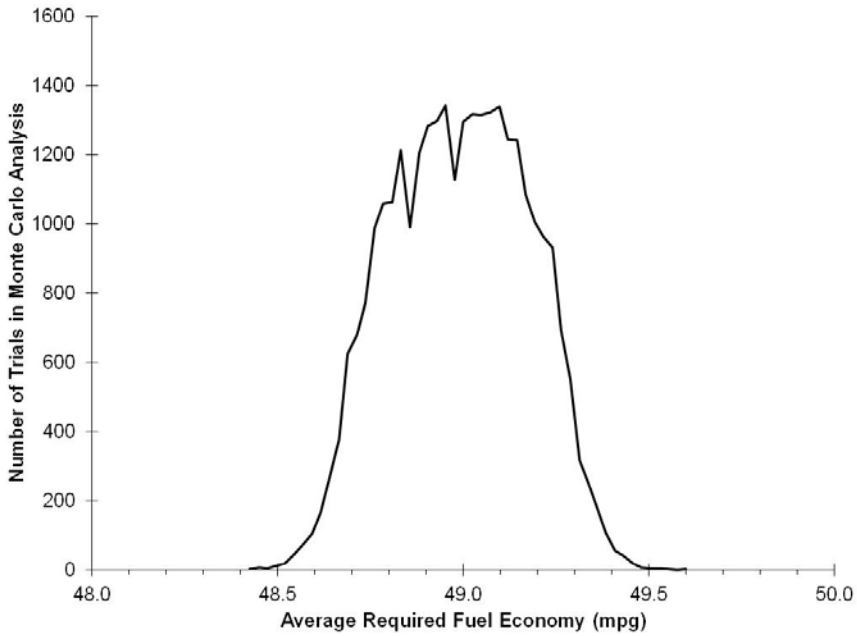
prices and shorter payback periods result in less. Manufacturers' assumption about the payback period (in years) desired by new vehicle buyers was drawn from a Poisson distribution that placed the highest probability on the value used in the central analysis.



Results

Some variables exhibited very little influence on the distribution of net benefits. For example, the energy security externality resulted in similar distributions of net benefits across the range of values considered. The limited consideration of market uncertainty produced similarly minor shifts. Despite the inclusion of a relationship that modifies the share of passenger cars in the new vehicle market, the average required fuel economy varied only slightly around the value in the central analysis. The graph below shows the resulting variation.

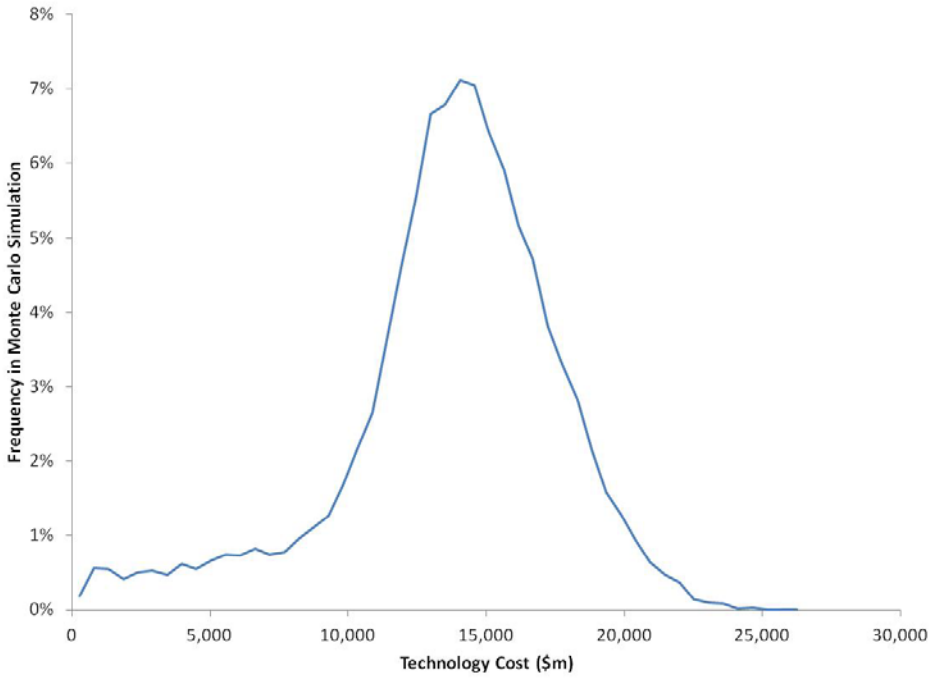
Average Required Fuel Economy (mpg) in MY2025



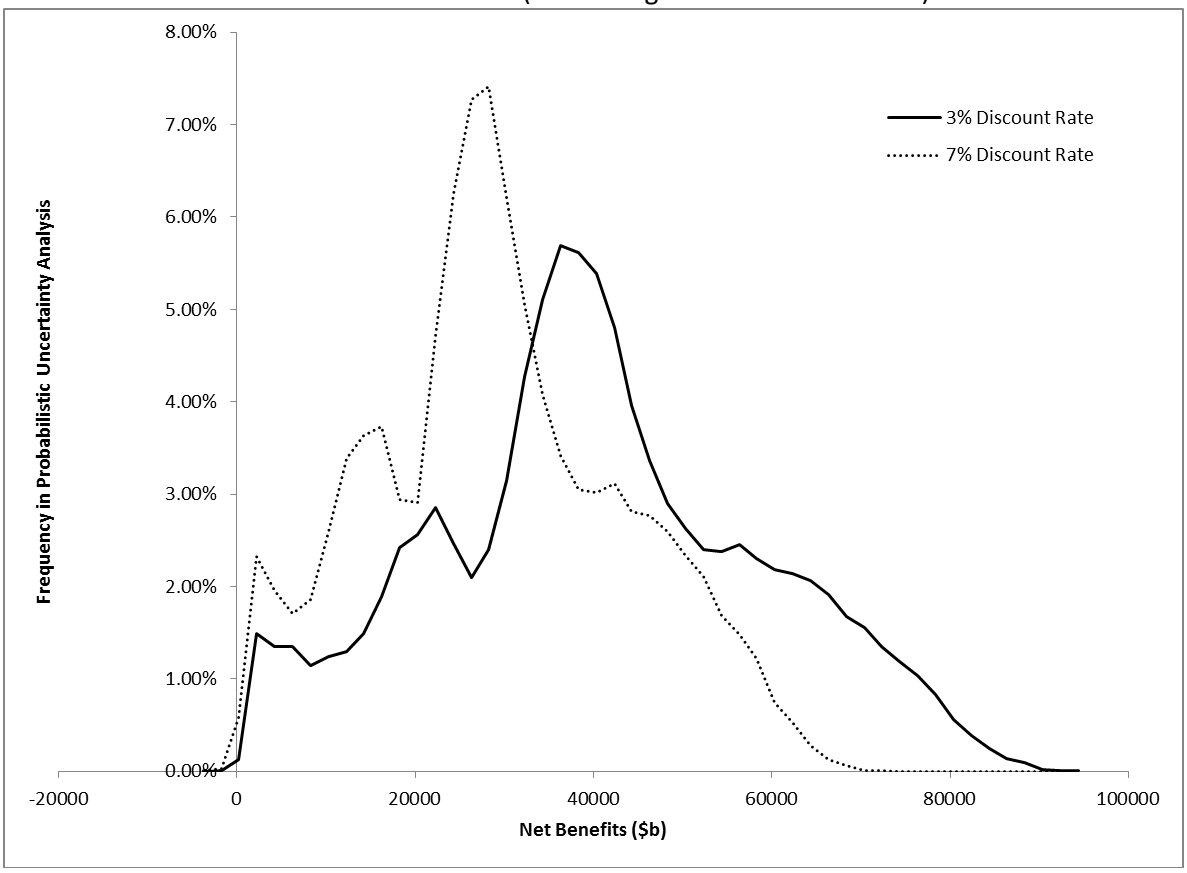
Technology costs exhibited more variation at both the high and low ends for the industry as a whole. For example, in MY 2021 the majority of the technology cost outcomes occur around $15 billion (the industry tech cost for MY 2021 in the central analysis is about $14.9 billion), but these central cases are bookended by very inexpensive cases and very costly ones (though in much smaller frequencies). The graph below shows the distribution of total technology cost for MY 2021.

The uncertainty analysis, similar to the central analysis, is conducted using both a 3% and a 7% discount rate. While the direction of the impact of using a higher discount rate is obvious, the adjacent figure provides a sense of the magnitude of the impact, which grows over successive model years.

Technology Cost in MY2021

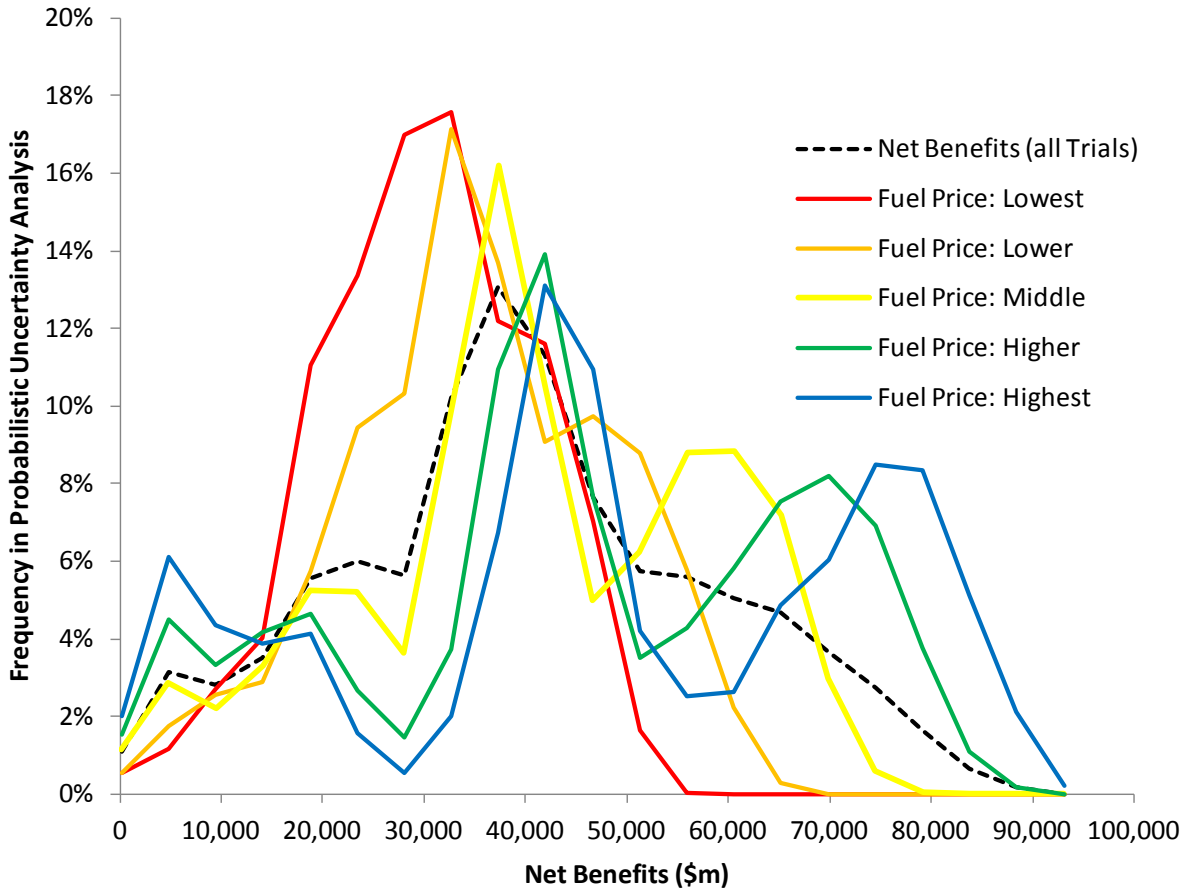


MY 2021 Net Benefits (Illustrating Role of Discount Rate)



Variation in fuel price draws has the ability to change both the shape of the distribution of net benefits and its scale. As one would expect, lower fuel prices lead to lower net benefits (reducing the value of each gallon of fuel saved), but also lead to narrower, single-peaked distributions. Higher fuel price draws created more nuanced distributions with multiple inflection points. Fuel prices interact with technology application (influencing the effective cost of each technology, making more expensive technologies more cost effective in earlier model years, shortening the payback period for more advanced technologies) and the benefit accounting (changing the value of each gallon of fuel saved and the impact of the rebound effect).

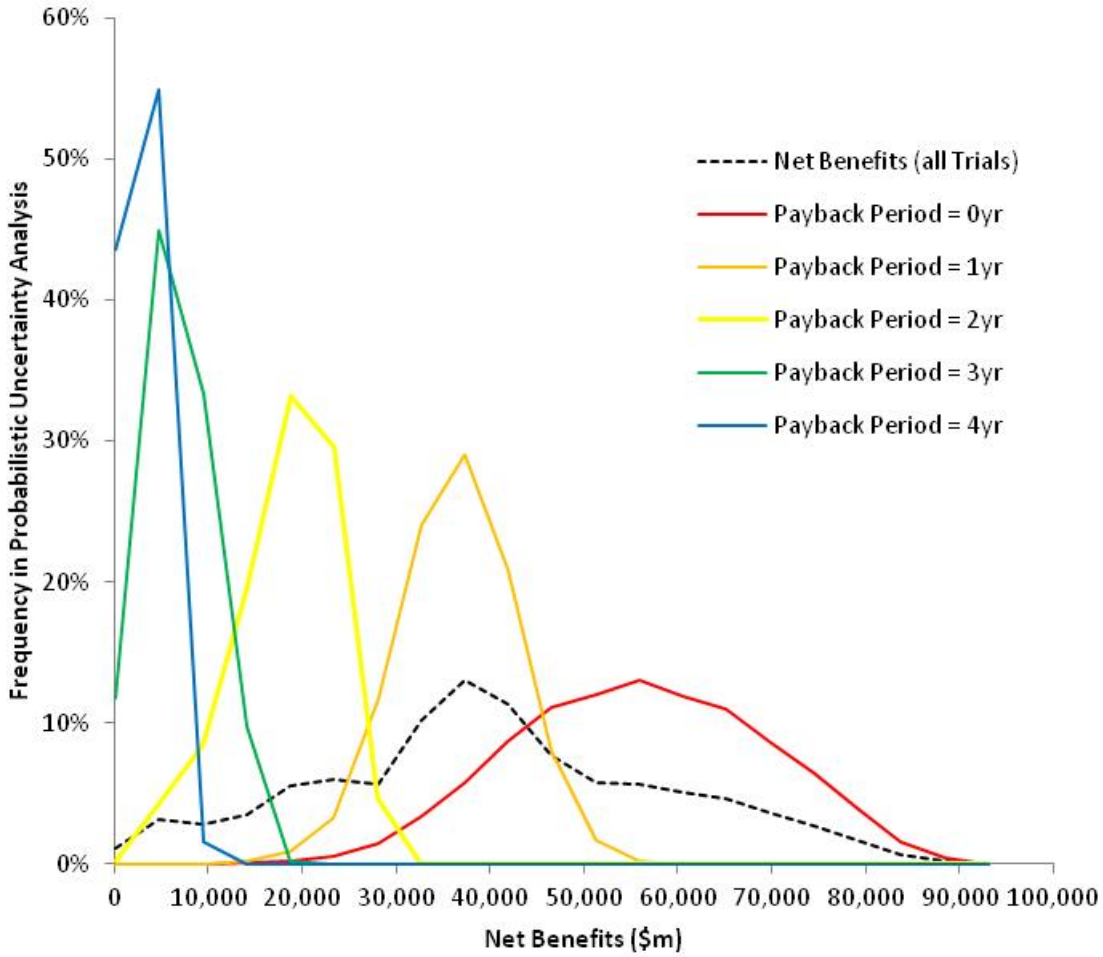
Impact of Fuel Price on Distribution of Estimated MY2021 Net Benefits

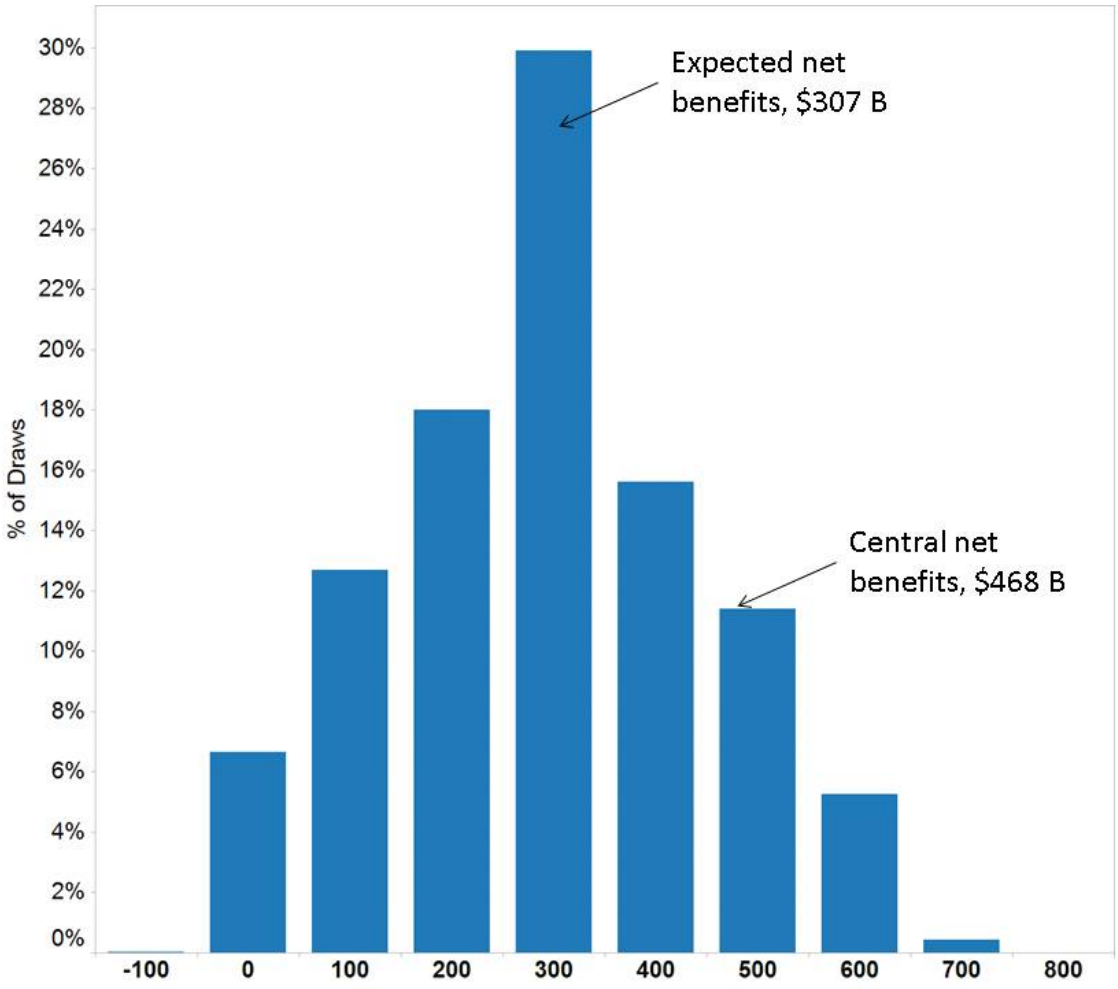


As one would expect, varying the payback period assumption increased the amount of technology application (and hence, fuel economy) in the baseline. It's worth noting that the distribution (shown above) of achieved industry-wide fuel economy was still relatively narrow, despite the influence of the market. This implies that similar levels of conservation were achieved across a broad range of assumptions about fuel prices and payback periods, but that variation in the accounting and attribution of savings impacted net benefits. Low fuel price cases reduced the value of fuel saved (just as high prices increased it) and more aggressive market adoption of fuel economy technology reduced the benefits

that could be attributed to the rule. The influence of the payback period variation across the entire set of draws is illustrated below.

Impact of Payback Period on Distribution of Estimated MY2021 Net Benefits



Overall, the expected value of net benefits differed from the point estimate in the central analysis once uncertainty was considered. The graph below shows the distribution of total program net benefits across all model years, identifying the values associated with the expected net benefits and the net benefits estimated in the central analysis. Although the two differ, the expected net benefits of the program are still significantly positive.

Distribution of net benefits, all draws