Fuel Economy and CO2 Emissions Standards, Manufacturer Pricing Strategies, and Feebates

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ABSTRACT

Corporate Average Fuel Economy (CAFE) standards and CO_2 emissions standards for 2012 to 2016 have significantly increased the stringency of requirements for new light-duty vehicle fuel efficiency. This study investigates the role of technology adoption and pricing strategies in meeting new standards, as well as the impact of feebate policies. The analysis is carried out by means of a dynamic optimization model that simulates manufacturer decisions with the objective of maximizing social surplus while simultaneously considering consumer response and meeting CAFE and emissions standards. The results indicate that technology adoption plays the major role and that the provision of compliance flexibility and the availability of cost-effective advanced technologies help manufacturers reduce the need for pricing to induce changes in the mix of vehicles sold. Feebates, when implemented along with fuel economy and emissions standards, can bring additional fuel economy improvement and emissions reduction, but the benefit diminishes with the increasing stringency of the standards.

Keywords **–** CAFE, emission standards, manufacturer pricing, feebates, nested multinomial logit (NMNL), optimization

INTRODUCTION

Corporate Average Fuel Economy (CAFE) Standards, established by the U.S. Energy Policy and Conservation Act of 1975, require automobile manufacturers to meet minimum fleet average fuel economy standards for passenger cars and light trucks. Their effectiveness and impacts on social welfare have been extensively studied in the literature (*1–6*). Two studies of manufacturer pricing strategies are particularly relevant to this paper. In meeting CAFE, a manufacturer may increase the price of its fuel-inefficient vehicles and/or decrease the price of fuel-efficient vehicles so that sales are shifted toward fuel-efficient vehicles and average fuel economy is increased. Greene (*1*) analyzed the use of short-run pricing strategies to shift sales to achieve a required fuel economy target and concluded that pricing strategies are efficient for small improvements in fuel economy but are expensive for large improvements. On the other hand, Thorpe (*2*) discussed un-intended effect of pricing. Thorpe found that the CAFE standards may contribute to the decrease of fleet fuel efficiency by inducing undesired inter-firm and cross market segment sales shift. A manufacturer's pricing strategies increase price of its fuel-inefficient vehicles and may shift consumers to similar vehicles with even lower fuel efficiency from another manufacturer or market segment which is less constrained by the standards and does not use pricing. He argued that the CAFE program has led to a shift toward luxurious and fuel-inefficient imported Asian cars and also contributed to the increased market share of light trucks, which have less restrictive standards. Both Greene and Thorpe focused on the short-run response of manufacturers, where the adoption of fuel economy technologies was not an option.

This paper evaluates the role of manufacturers' technology adoption and pricing strategies in meeting new CAFE standards (2011–2016) and CO_2 emissions standards (2012–2016), assuming the use of currently available, proven technologies. Although pricing is an important tool that manufacturers may use to cope with uncertainties in production, consumer demand, and fuel price fluctuation, inducing technology adoption is the intended purpose of the regulation. Thus an examination of the relative role of technology adoption and pricing strategies helps us understand the functionality of new standards. Another objective of the paper is to determine whether or not the standards would induce an undesired sales shift toward fuel-inefficient vehicles. We also examine the impact of a feebate program implemented along with CAFE and emissions standards on manufacturer decisions and fuel efficiency improvement. A *feebate* is a market-based policy that levies fees on new vehicles with low fuel efficiency and provides rebates to new vehicles with high fuel efficiency (*7*).

The effects of CAFE and emissions standards on manufacturer decisions and vehicle sales mix shifts are estimated using a dynamic multi-period optimization model. Under the assumption of a competitive or monopolistically competitive market, manufacturers maximize social surplus (the summation of consumer and producer surplus) by optimizing their technology adoption and pricing decisions subject to CAFE and emissions standards. Fuel economy improvement and pricing strategies induce changes (relative to the base year) in vehicle price and operating cost. The impact of these changes on consumer demand and surplus is estimated by a nested multinomial logit (NMNL) model. Both manufacturer decisions and consumer demand are modeled at the level of vehicle configuration (a combination of vehicle make, model, engine size and transmission type) corresponding to the level of detail at which fuel economy measurements are made by the U.S. Environmental Protection Agency (EPA). Compared with recent CAFE analysis models (*3*,*4*), the advantages of our approach are 1) more realistic modeling of technology adoption by including vehicle redesign cycles and 2) more accurate simulation of sales mix shifts by representing consumer choices at the greatest feasible level of detail.

In the remainder of this paper, we first provide more background on new CAFE and emissions standards. We then introduce the dynamic optimization model and define reference and policy scenarios. Finally, we summarize primary results and present our conclusions.

CAFE (2011–2016) and CO_2 Emissions (2012–2016) Standards

New standards have substantially tightened requirements for new light-duty vehicle fuel efficiency, compared with old standards (2010 and before). Moreover, the fuel efficiency target of a vehicle is a function of its footprint (wheelbase × track width). The standards define footprint functions separately for cars and light trucks and for each model year (*8*). A manufacturer must separately meet the standards for cars and light trucks: The sales weighted harmonic mean fuel economy for a manufacturer's car or truck fleet is required to exceed its harmonic mean fuel economy target for the case of CAFE standards; the sales-weighted mean CO_2 emissions must not exceed the sales-weighted CO_2 emissions target for the case of emissions standards. For instance, emissions standards for a manufacturer's car fleet can be described by the following equation:

$$\sum_{i=1}^{m_N} \frac{Sale_i(t)}{Sale_m(t)} (e_i(t) - e_i^*(t)) \le 0 \text{ , } \forall t, m \qquad (1)$$

where m_N denotes the number of car models produced by manufacturer *m*, $Sale_i(t)$ represents the sales of car model *i* for year *t*, $Sale_m(t)$ is the total sales of all cars produced by manufacture *m*, $e_i(t)$ is the emissions rate of model *i*, and $e_i^*(t)$ is its emissions target, calculated by the footprint functions given in the standards.

New standards also provide compliance flexibility to manufacturers. Manufacturers can earn compliance credits by exceeding the required target. Credits can be banked and borrowed within a five-year period to offset any deficit in a model year. Manufacturers can also achieve flexible fuel vehicle (FFV) credits and air conditioning (AC) credits by producing FFVs and improving air conditioning systems. The most prominent new feature is to allow credit transfer between compliance categories of cars and trucks within a firm and credit trading among firms. As Rubin et al. (*9*) pointed out, credit trading can reduce manufacturers' compliance cost by 7% to 16%.

METHODOLOGY

Our approach integrates manufacturer decisions and consumer demand in one multi-period optimization framework. Detailed documentation of the model, its coefficients, calibration, and data are available (*10*). A brief overview is provided here.

Manufacturer Decisions

The manufacturer decision problem is described by an optimization model that maximizes social surplus subject to the requirements of CAFE and emissions standards. In meeting the standards, manufacturers have various options, including

1. adopting fuel economy technologies that increase fuel economy at a cost

2. implementing pricing strategies that adjust vehicle prices in order to shift sales toward fuel-efficient vehicles and thus increase fleet average fuel efficiency
3. buying compliance credits from other firms
4. obtaining AC and FFV credits by improving air conditioning system and producing FFVs, and
5. using banked or borrowed credit.

The first three options are formulated in the model. AC and FFV credits are included exogenously. Banking and borrowing is not allowed, although this restriction will be relaxed in sensitivity analysis.

Technology Cost Curves

The technical potential to improve fuel economy is represented by technology cost curves that take into account base year implementation of fuel economy technologies as well as future potential applicability. Technology cost curves (provided by ICF International (*10*)) describe the cost of increasing fuel economy in the form of quadratic functions relating incremental retail price equivalent (RPE) to relative increase in fuel economy (Figure 1). The RPE is intended to represent the long-run average cost of fuel economy technology, including a normal rate of profit. In effect, this implies either competitive or monopolistically competitive market conditions (firms may differentiate products, but on average, products are priced at their long-run average cost). Separate technology cost curves are provided by vehicle class (20 vehicle classes), engine technology (gasoline, diesel, and hybrid vehicles), and time period (short-, medium- and long-term).

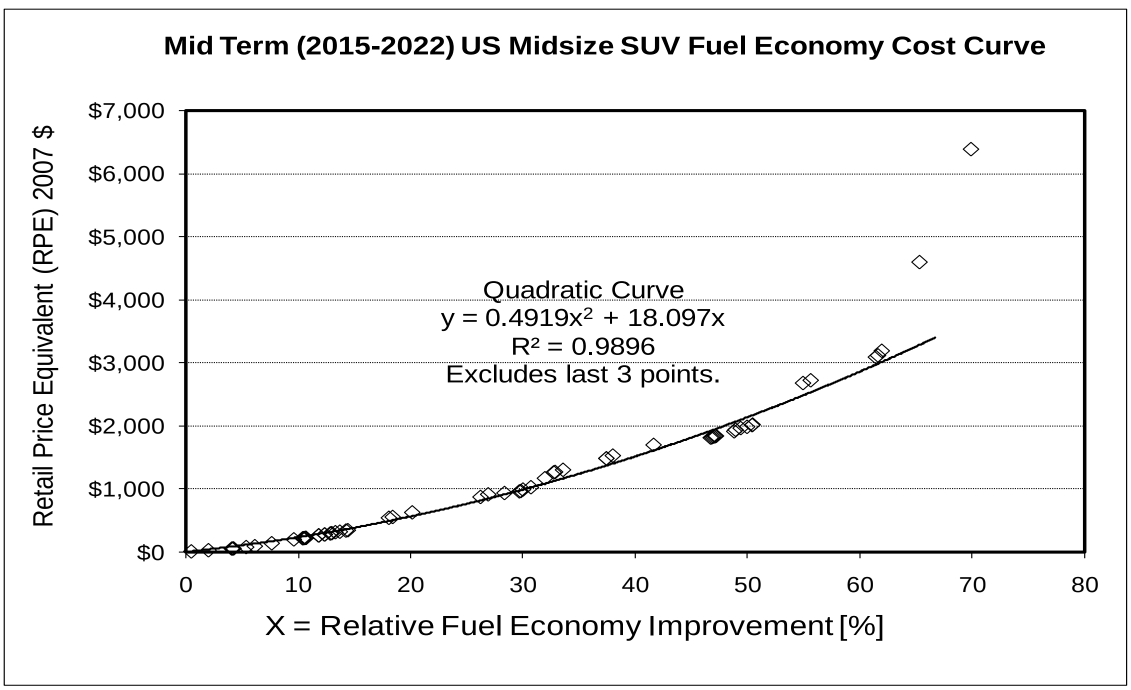

FIGURE 1 Mid-term (2015–2022) U.S. midsize SUV fuel economy cost curve based on spreadsheet models provided by ICF International, Inc., 2009.

Optimization Model Equations

The optimization model has multiple variants, depending on model assumptions. The basic version of the model is described by the following equations:

$$\max \sum_t \{(1+r)^{-t} MS(t)[\Delta CS(t) + S_{Buy}(t)\sum_i S_i(t)\Delta p_i(t)]\} \qquad (2)$$

such that

$$\sum_{i=1}^{N} S_i(t) e_i(t) \le \sum_{i=1}^{N} S_i(t) e_i^*(t) \text{ , } \forall t, \qquad (3)$$

$$e_i(t) = e_i(t-1), \text{ if vehicle } i \text{ is not redesigned in year } t. \qquad (4)$$

The decision variables are fuel efficiency (in fuel consumption or CO_2 emissions rate) level e_i and price adjustment Δp_i for each vehicle configuration for each model year. Other vehicle characteristics (e.g., vehicle weight, size and horsepower) are assumed to be unchanged over the planning horizon. The objective function (2) is accumulated total social surplus over the planning horizon, where *r* is the discount factor, *MS* is market size represented by the number of households, ΔCS is consumer surplus change per household relative to the base year, S_{Buy} is market share of buying a new vehicle and S_i is conditional market share of vehicle configuration *i* given consumers have chosen to buy a new vehicle. Both ΔCS and S_{Buy} are functions of decision variables and calculated by the NMNL model (see next section on Consumer Demand). The second part of the objective function is producer surplus (total profit from pricing). Assuming full credit trading among car and truck categories and among firms, constraint (3) formulates manufacturer-specific CAFE and emissions standards as one industry-wide constraint, as if there is only one big manufacturer in meeting standards. In the constraint e_i^* is the fuel efficiency target of vehicle *i* and *N* is the total number of vehicle configurations in the market. Note that either fuel economy or emissions standards can be selected as constraints since they have equivalent stringency in regulating manufacturers' fleet fuel efficiency. Constraint (4) restricts that a vehicle's fuel efficiency can only be improved in its redesign years.

It is proved in (10) that the producer surplus from pricing is zero when optimal solutions are achieved. Moreover, manufacturers' optimal pricing strategy is

$$\Delta p_i(t) = \lambda(t)(e_i(t) - e_i^*(t)), \lambda(t) \ge 0, \forall t, \qquad (5)$$

where λ is the pricing rate, proportional to the multiplier (shadow price) of constraint (3). That is, manufacturers will charge more for vehicles whose fuel consumption/emissions rates are above the target level specified in the standards and subsidize vehicles whose fuel consumption/emissions rates are below it. The charges and subsidies are proportional to a vehicle's deviation from the standards. Thus, objective function (2) can be equivalently written in the following form (6). The advantage of this expression is that, by replacing pricing variable $\Delta p_i(t)$ with pricing rate $\lambda(t)$, there are many fewer decision variables.

$$\max \sum_t \{(1+r)^{-t} MS(t)[\Delta CS(t) + S_{Buy}(t)\sum_i S_i(t)\lambda(t)(e_i(t) - e_i^*(t))]\} \qquad (6)$$

Manufacturers may also convert an existing gasoline internal combustion engine (ICE) vehicle to a hybrid electric vehicle (HEV), which is more fuel-efficient but also incurs a price premium. This option is modeled by binary decision variables to determine which vehicle configurations will be hybridized and when. The conversion cost (price premium) turns out to be a key parameter impacting the hybridization decision. Prior to 2014, this cost is assumed to be 1.5 times the vehicle's curb weight. Thus, for a 3,000-lb. car, the conversion cost would be $4,500. This drops to 1.0 times the curb weight in 2014 and 0.75 times the curb weight in 2018. These assumptions are consistent with Bandivadekar, et al (*11*), but have been brought forward ten years.

Consumer Demand

Consumer demand is represented by a NMNL model with a representative consumer. All vehicle attributes except fuel efficiency and price are assumed to remain constant over the period of analysis. Consumers are assumed to value future fuel savings using a simple three-year payback rule, implying an undervaluing of the discounted present value of lifetime fuel savings by a factor of two or more. The change in vehicle net value (incremental technology cost less fuel savings and plus any price adjustment) is input to the NMNL model. Consumer surplus and vehicle sales and market shares are calculated as functions of the change.

Choice alternatives are represented in detail at the level of make, model, engine and transmission configuration. Alternatives are grouped into nests as in Figure 2 to allow differential substitution patterns within and between nests. The nesting structure begins with a "buy/no-buy" decision at the top level, followed by the choice between a passenger vehicle and a work truck (pick-up or standard van). Subsequent levels distinguish among vehicle sizes and luxury versus standard vehicles. At the penultimate level, there are 20 different vehicle classes. The bottom level includes over 800 vehicle configurations. Utility expression for each nest has two associated parameters, alternative specific constant term and price slope. For example, the utility for vehicle *j* in class *k* is

$$U_{jk} = A_{jk} + B_k(C_{jk} - FS_{jk} + \Delta p_{jk}) + \varepsilon_{jk} = A_{jk} + B_k(C_{jk} - FS_{jk} + \lambda(e_{jk} - e^*_{jk})) + \varepsilon_{jk}, \quad (6)$$

Where

A_{jk}: constant term for vehicle *j* in class *k*,

B_k: price slope parameter for vehicles in class *k*,

C_{jk}: incremental cost for improving fuel economy of vehicle *j*, and

FS_{jk}: the amount of fuel savings from improved fuel economy, valued by consumers when making purchase decisions.

Δp_{jk}: manufacturer price adjustment, which is equal to $\lambda(e_{jk} - e^*_{jk})$ as discussed in equation (5).

The NMNL constant terms was calibrated to exactly match the shares of vehicle configurations in the base year of 2007 and total sales as predicted by the 2010 Reference Case in the Energy Information Administration's *Annual Energy Outlook* (*12*). The NMNL price slopes were derived from price elasticities reported in the literature.

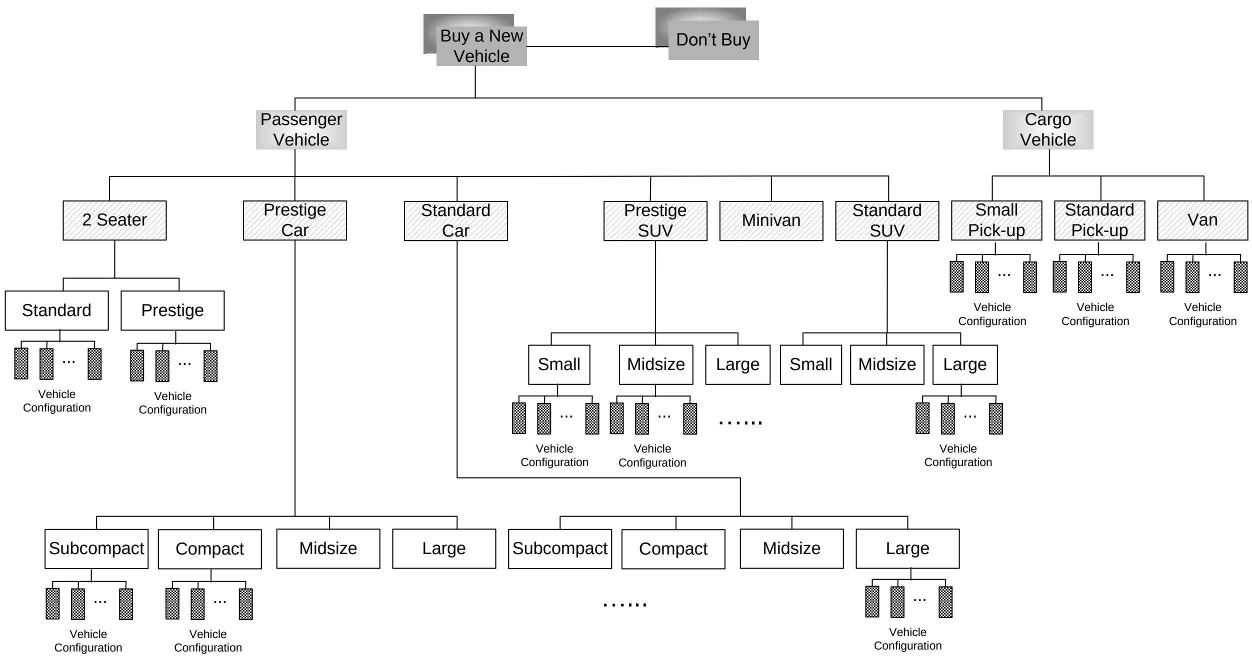

FIGURE 2 Nesting structure of the NMNL model.

RESULTS

Scenario Descriptions

The primary purpose of the analysis is to investigate the relative role of technology adoption and pricing in complying with the standards. It is done by comparing the base and reference cases. The reference case has no CAFE or emissions standards in effect, but manufacturers may still want to improve fuel efficiency if the benefit of fuel cost savings outweighs the technology cost. The base case assumes that 2011–2016 CAFE and 2012–2016 emissions standards are in place. The analysis period is 2011–2020. Post-2016 standards are assumed to follow EPA and the National Highway Transportation Safety Administration's (NHTSA's) recently announced plan to increase the stringency of the standards by 5% each year for cars and 3.5% each year for light trucks (*13*). Manufacturers are allowed to use both technology adoption (including converting vehicles to hybrids) and pricing to comply with the standards. Manufacturers can also achieve AC and FFV credits by improving air conditioning systems and producing FFVs. Our model does not formulate manufacturers' decisions regarding air conditioner improvement or FFV production. The credits are directly granted to manufactures at the industry level according to the amount estimated by the EPA (page 25409 of (*8*)), which essentially relaxes the stringency of the standards.

TABLE 1 Scenarios Analyzed in the Study

Scenario	Scenario Name	Scenario Description
1	Reference	No Standards

2	Base	Standards in place, manufacturers use both technology adoption and pricing in response to standards
3	No AC and FFV Credits	Base case assumption and manufacturers are not permitted to obtain AC and FFV credits
4	Banking	Base case assumption and manufacturers can bank compliance credits for future use.
5	Reference - Low Hybridization Cost	Reference case assumption and lower hybridization cost
6	Low Hybridization Cost	Base case assumption and lower hybridization cost
7	Reference-Low Elasticity	Reference case assumption and lower price elasticities
8	Low Elasticity	Base case assumption and lower price elasticities
9	Reference-High Elasticity	Reference case assumption and higher price elasticities
10	High Elasticity	Base case assumption and higher price elasticities
11	Feebate	Base case assumption and a feebate program in place

Cases 3 to 10 are constructed to test the sensitivity of results with respect to model assumptions. Case 3, No AC and FFV Credits, disables manufacturers' option of obtaining AC and FFV credits. Case 4 allows manufacturers to bank compliance credits in addition to base case assumptions. As discussed in the methodology section, hybrid conversion cost is a key parameter for determining if it is cost effective to convert a gasoline vehicle to a hybrid. Case 6 uses a low hybridization cost assumption: Prior to 2014, this cost is assumed to be 1.5 times the vehicle's curb weight. This drops to 1.0 times the curb weight in 2014 and 0.5 times the curb weight in 2017. The low cost assumption uses the same conversion cost as the default assumption before 2016 and assumes a lower cost after that. Case 5 is case 6's reference case.

As discussed in section on Consumer Demand, price elasticities are key input to calibrate the NMNL model. Thus cases 7 to 10 are designed to test the sensitivity of results with respect to price elasticities. Low elasticity cases assume elasticity values are 20% lower than in base case and high elasticity cases assume elasticity values are 20% higher than in base case.

Case 11, the Feebate case, evaluates the impact of a feebate program in addition to standards. Feebates are added to vehicle price, calculated according to the following formula: Feebates of a vehicle = feebate rate * (the vehicle's emissions rate – the vehicle's feebate benchmark). The feebate rate is $20 per gram CO_2 per mile. The feebate benchmark of the vehicle, where the vehicle gets no fees or rebates, is set at its emissions target defined by footprint functions of the standards. Feebates are assumed to be in effective for the whole period of 2010-2020.

For all cases, we assume that (1) vehicle fuel efficiency and price are the only vehicle attributes changed in the analysis period and that (2) consumers undervalue fuel savings from fuel economy improvement, counting only the first three years of savings.

Results

Role of Technology Adoption and Pricing

We first look at Figure 3 to check industry-wide sales weighted average CO_2 emissions for different cases. The base case curve first follows the unconstrained reference curve, becomes binding with emissions standards in 2016, then goes below standards in 2017 and 2018, and finally overlaps with standards again in 2019 and 2020. Note that manufacturers over-comply with the standards in 2017 and 2018, which can be explained by the vehicle redesign constraint. A vehicle can only be redesigned and fuel economy technologies can only be added once in an interval of four to five years. Thus, some vehicles cannot be redesigned in year 2019 and 2020. To cope with difficulties in meeting 2019 and 2020 standards, a good strategy may be to add technologies to these vehicles earlier in 2017 and 2018, even if it means over compliance. The banking case curve displays a different pattern. It is well below the curve of emissions standards before 2018, implying that manufacturers over comply in this period and bank compliance credits. These credits are used to help meet 2018-2020 standards and consequently actual average emissions level is higher than the standards. Note that there is an *end of period* effect here. Since the planning horizon of the optimization model is 2011-2020 and unused credits beyond 2020 will have zero value, the model tries to use up all banked credits within this period. This is generally not true in the real world, where unused credits can be carried forward to next period.

Table 2 displays the value of the pricing rate (λ in equation(5)), which directly determines the scale of manufacturers' price adjustment. Consistent with Figure 3, the base case has a nonzero pricing rate only in the three years when emissions standards are binding. Table 3 calculates the proportion of emissions reduction (relative to the reference case) due to pricing. Both technology adoption and pricing contribute to the reduction of the sales-weighted average emissions. The following procedure explains how to decompose total emissions reduction into proportions due to technology and pricing respectively: First solve the model and obtain the solutions of fuel efficiency, price adjustment level and sales for each vehicle for each year. Sales-weighted average emissions and emissions reduction relative to the reference case are calculated. Second, fix fuel efficiency at the level in the solutions and re-solve the model with the pricing option disabled. Calculate sales-weighted average emissions and emissions reduction again. Emissions reduction here is the proportion due to technology. Table 3 shows that emissions reduction due to pricing is moderate in the base case, at most 4% to 5%, when pricing does exist.

If manufacturers are not permitted to obtain AC and FFV credits, the emission standards turn out to be quite stringent. Pricing is used to meet the standards for most years of the analysis period (see No AC and FFV credit case in Table 2). The proportion of emissions reduction due to pricing is around 3% to 10%, but could be as high as 22% for an individual year (Table 3).

The allowance of banking provides manufacturers with greater flexibility in meeting standards. The Banking case in Table 2 and 3 demonstrates the possibility of applying pricing to accumulate credits even when the standards are not binding (e.g. in 2014). The scale of pricing is moderate, with emissions reduction due to pricing at 1% to 4%.

The Low Hybridization Cost case in Tables 2 and 3 shows that a significant reduction in hybrid conversion cost after 2016 can greatly help manufacturers meet the standards and alleviate the need for pricing. The proportion of emission reduction due to pricing is small, 2% at most.

The usage of pricing in low and high elasticity cases share similar pattern and scale to the base case. It is interesting to note that the scale of pricing rate (Table 2) is smaller in high elasticity case than in low elasticity case, but the reverse is true for emissions reduction due to pricing. Compared with low elasticity case, consumer demand in high elasticity case is more sensitive to price adjustment and thus smaller price change leads to even larger sales shift.

Rebound Effect

Another issue of interest is the potential for a fuel efficiency rebound effect. One conjecture is that the fleet-wide fuel efficiency improvement may make some fuel-inefficient vehicles more attractive (e.g., sports cars are more fuel-efficient than before and may attract new buyers who like performance but also care about fuel cost) and shift sales toward these vehicles. Thorpe (*2*) argued that it is manufacturers' pricing strategies that induce sales shifts toward fuel-inefficient cars and light trucks. A manufacturer with binding standards increases price of its fuel-inefficient vehicles in order to meet the standards. It may shift consumers to similar vehicles with even lower fuel efficiency from another manufacture or market segment which is less constrained by the standards and does not use pricing. Theoretically speaking, the new standards with the permission of credit trading equalize marginal compliance cost across firms and car and truck categories and thus will eliminate un-favored sales shifts described by Thorpe (*2*).

We quantify the rebound effect by first calculating the sales-weighted average emissions reduction $\overline{\Delta e}$ for each case relative to the reference case

$$\overline{\Delta e} = \sum_i (S_i^0 e_i^0 - S_i e_i), \qquad (6)$$

and then re-computing the emissions reduction numbers $\overline{\Delta e}'$ using the sales mix in the reference case

$$\overline{\Delta e}' = \sum_i (S_i^0 e_i^0 - S_i^0 e_i). \qquad (6)$$

In equations (6) and (6), S_i^0 and S_i are market share of vehicle *i* in reference case and policy case (one of cases 2,3,4,6,8,10) respectively, and e_i^0 and e_i are emissions rate of vehicle *i* in reference case and policy case respectively. If the second emissions reduction number is bigger than the first one, there is a rebound effect, quantified by the ratio of the difference of these two reduction numbers over the second number, i.e., $(\overline{\Delta e}' - \overline{\Delta e}) / \overline{\Delta e}'$. These ratios are reported in Table 4, where positive ratios indicate the existence of a rebound effect and negative ratios indicate that sales are shifted toward fuel-efficient vehicles. Our result suggests that the rebound effect is minor, when it exists at all, and that sales are shifted toward fuel-efficient vehicles in nearly all cases.

Impact on Average Vehicle Footprint

Table 4 has shown that sales are shifted toward fuel-efficient vehicles in most cases. Does this in turn imply a shift toward small vehicles which have relatively high fuel efficiency? Table 5 records the percentage change of industry-wide average footprint in base and sensitivity cases relative to average footprint in the reference cases. For all cases, the change is minimal. This result is consistent with the design feature of the footprint-based new standards. Sales are shifted toward vehicles whose fuel efficiency are higher than their footprint-based targets, and not necessarily toward small size vehicles.

Feebates

As discussed in the methodology section, manufacturers' optimal pricing strategy is equivalent to a self-applied internal feebate system, as described by equation (5). The pricing rate λ is the feebate rate of the internal feebate system, and the emissions target is the feebate benchmark. A governmental feebate system plays a similar role to the manufacturers' internal feebate system. Thus the implementation of feebate policies will avoid or reduce the need for manufacturers to make use of pricing.

As shown in Table 2, manufacturer pricing is not needed under a feebate program with a $20 feebate rate. Figure 4 shows that this feebate program can reduce emissions by 20–30 grams of CO_2 per mile relative to the base case. However, the reduction due to feebates diminishes in the outer years of the analysis period, because the standards are becoming increasingly binding and feebates are used by manufactures to replace their pricing strategies to meet the standards.

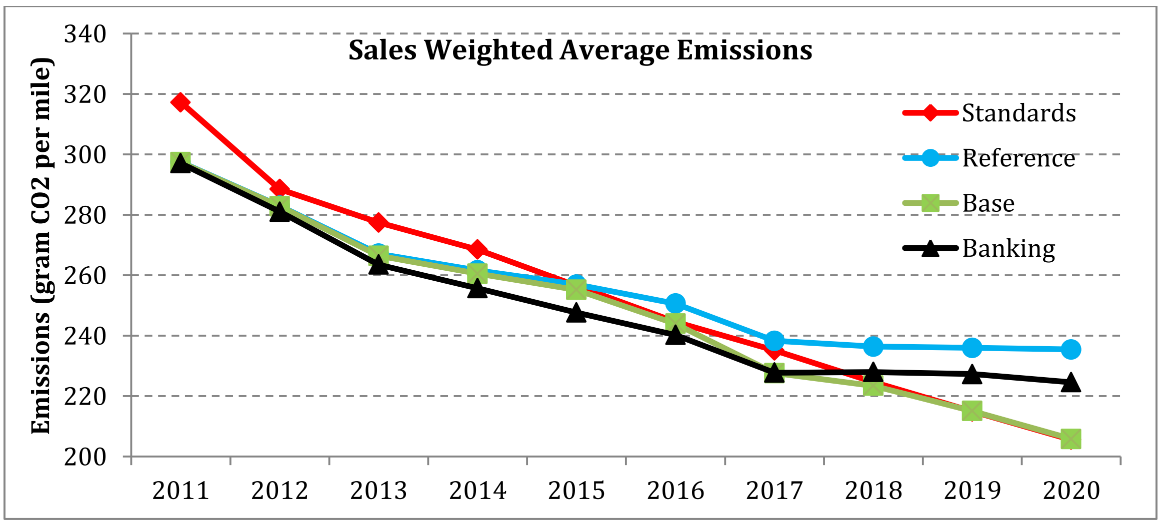

FIGURE 3 Average emissions for emissions standards, reference case and base case.

TABLE 2 Value of Manufacture Pricing Rate (λ in equation(5)) in Different Scenarios

Scenario Name	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Base						4.8			12.4	19.6
No AC and FFV Credits		9.0			12.4	16.7		10.5	30.0	34.9
Banking				2.2	5.9	6.0	5.7		2.1	5.4
Low Hybridization Cost						2.6			0.3	
Low Elasticity						5.3			12.6	20.5
High Elasticity						4.4			12.1	18.9

Feebate										

TABLE 3 Proportion of Emissions Reduction Due to Pricing

Scenario Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Base						4.2%			4.2%	5.3%
No AC and FFV Credits		22.0%			9.0%	10.0%		2.7%	6.5%	6.4%
Banking				2.9%	4.4%	3.8%	2.0%		1.0%	1.8%
Low Hybridization Cost					0.8%	2.2%			0.4%	
Low Elasticity						3.7%			3.4%	4.4%
High Elasticity						4.6%			5.0%	6.2%

TABLE 4 Rebound Effect of the Standards

Scenario Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Base	0.1%					-4.4%	-0.1%		-4.5%	-5.8%
No AC and FFV Credits	-12.5%	-30.2%		-0.2%	-10.1%	-11.4%	-0.4%	-3.1%	-7.3%	-6.9%
Banking	0.3%	0.1%	-0.1%	-2.5%	-5.6%	-4.9%	-2.7%	-0.1%	-1.0%	-2.3%
Low Hybridization Cost				0.1%	0.2%	-0.8%	0.2%	0.2%	0.3%	0.6%
Low Elasticity	0.1%					-3.9%	-0.1%	0.0%	-3.6%	-4.8%
High Elasticity	0.1%					-4.8%	-0.1%	0.0%	-5.4%	-6.9%

Table 5 Impact on Fleet Average Footprint

Scenario Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Base						-0.2%			-0.3%	-0.4%
No AC and FFV Credits		-0.4%			-0.3%	-0.5%	-0.1%	-0.3%	-0.6%	-0.6%
Banking				-0.1%	-0.1%	-0.2%	-0.1%		-0.1%	-0.1%
Low Hybridization Cost						-0.1%			-0.1%	-0.1%
Low Elasticity						-0.1%			-0.2%	-0.4%
High Elasticity						-0.2%			-0.3%	-0.5%

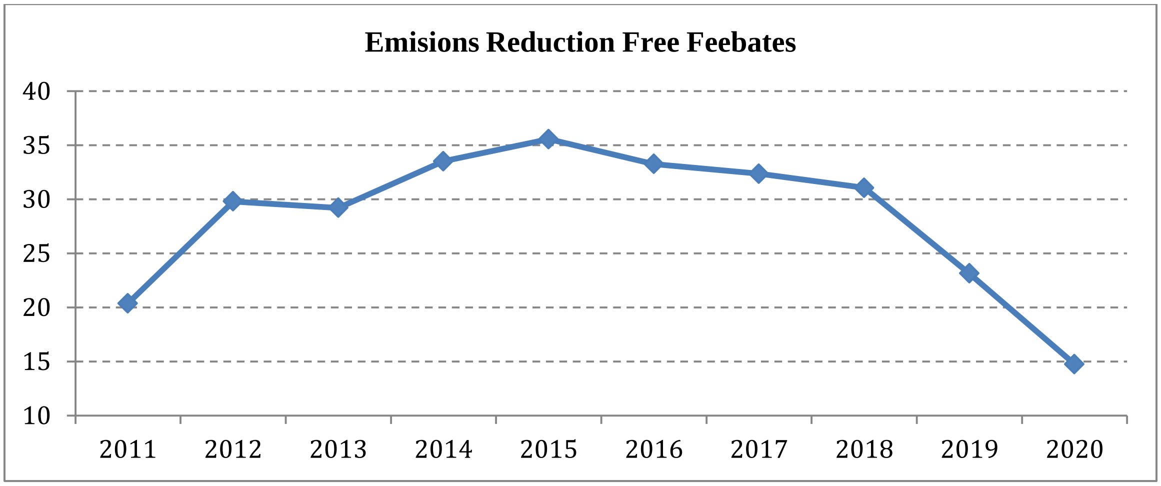

FIGURE 4 Emissions reduction from the feebate program with a $20 feebate rate.

CONCLUSION

Our analysis indicates that technology adoption plays the major role in meeting new CAFE and emissions standards. Pricing is minor for most of the analysis period but may be employed in outer years if cost-effective technologies are less plentiful. Emissions reduction due to pricing is moderate, at around 4% to 5% when pricing does exist. The provision of flexibility mechanisms turns out to be a great help to manufacturers for meeting standards. It is demonstrated by significantly increased usage of pricing strategies when AC and FFV credits are disabled. The allowance of banking helps to reduce the need of pricing strategies in outer years by applying pricing in earlier years to bank compliance credits. The availability of cost-effective advanced technologies (hybrids in this study) after 2016 is also important to the effectiveness of the standards. Feebates, when implemented along with the standards, can bring additional emissions reduction, but the benefit may diminish over time if feebates act as a replacement for manufacturers' pricing strategies when standards are increasingly binding.

Our simulation results also indicate that the new standards are unlikely to produce unfavorable rebound effect of shifting sales toward fuel-inefficient vehicles. Instead, the standards appear likely to induce sales shifts toward fuel-efficient vehicles. The allowance of credit trading equalizes marginal compliance cost across cars and trucks categories and across firms. Thus it removes the incentive for undesired sales shifts as in Thorpe (*2*). Furthermore, our results find no evidence of sales shifts toward small size vehicles by examining fleet average footprint. One possible reason is that manufacturers faced with foot-print based standards have the incentive to shift sales toward vehicles whose fuel efficiency are higher than their footprint-based targets, and not necessarily toward small size vehicles.

The analysis has multiple caveats. First, the assumption of full credit trading among cars and trucks and among manufacturers is ideal, although it is believed to be close to the real credit market in the long run. If the credit trading market turns out to be inefficient, individual manufacturers may still face binding standards and apply pricing strategies. Second, some fuel-efficient technologies can also be used to improve performance. This study has not included the tradeoff between fuel efficiency and performance and assumes that these technologies are all used to improve fuel efficiency. There is a lack of consensus in the literature on the value of horsepower and its impact on fuel economy. In addition, vehicle performance and size can produce relative, as well as absolute, utility, implying that they currently may be over-consumed in the market. Attempting to adequately represent this situation would add complexity to the model in an area where an empirical basis for making the necessary assumptions is lacking. Finally, our technology package includes only proven technologies for conventional vehicles and HEVs. The impacts of plug-in hybrid electric vehicles (PHEVs) and other advanced technology vehicles were not measured in this analysis. Breakthroughs in advanced technologies would further reduce the need for applying pricing strategies.

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