RFF REPORT

New Markets for Credit Trading under US Automobile Greenhouse Gas and Fuel Economy Standards

Benjamin Leard and Virginia McConnell

MAY 2017

RESOURCES FOR THE FUTURE

New Markets for Credit Trading under US Automobile Greenhouse Gas and Fuel Economy Standards

Benjamin Leard and Virginia McConnell*

Abstract

Recent changes to the US Corporate Average Fuel Economy (CAFE) regulations that allow for credit banking and trading have created new opportunities for lowering the cost of meeting strict new standards. For the first time, automakers will be able to trade credits between their own car and truck fleets and across manufacturers, and they will be able to bank credits over longer time periods. The potential to lower the costs of the regulations could be large if well-functioning credit markets develop. A recent development is that new regulations starting in 2012 for greenhouse gas (GHG) emissions overlap with the CAFE standards, creating two separate regulations and two separate credit markets, one for fuel economy (regulated by the National Highway Traffic Safety Administration) and one for greenhouse gases (regulated by the Environmental Protection Agency). We find that although the two regulations are supposed to be harmonized, there are some important differences in how credits are defined and how they can be traded, creating added costs for manufacturers. We review evidence on how well the credit markets are working, including the extent of credit banking and the number and price of trades. We then assess the potential for the following to interfere with well-functioning markets: overlapping regulations, reductions that are not additional, thin markets, and use of monopoly power. We find that some features of robust trading are missing and discuss some possible ways to improve efficiency in these markets.

Key Words: credits, pollution markets, CAFE rules, GHG emissions reductions

---

*Leard: Fellow, Resources for the Future, leard@rff.org; McConnell: Senior Fellow, Resources for the Future, mcconnell@rff.org. This report is a revision of RFF discussion paper 15-16, originally published in May 2015.

Contents

1. Introduction **1**

2. Background and Overview of the New CAFE and GHG Credit Markets **1**

2.1. The CAFE and GHG Standards 1

2.2. Flexibility in the Credit Markets 2

2.3. Differences in how Credits are Defined 3

2.4. Differences in Banking Provisions 4

2.5. Differences in Emissions Averaging Between Car and Truck Fleets 5

2.6. Penalties for Noncompliance 5

2.7. Credits for Alternative Fuel Vehicles 5

2.8. Standards for Small Volume Producers 7

3. Empirical Evidence on Market Outcomes **7**

3.1. Credit Transfers between Cars and Trucks 7

3.2. Banking 8

3.3. Trading Across Manufacturers 9

3.4. Information on Credit Prices 11

4. Assessment of the Credit Trading Markets and Lessons From Other Pollution Regulations **12**

4.1. Overlapping Regulations 12

4.2. Are Emissions Reductions from the Regulations Additional? 13

4.3. Lack of Transparency and Thin Markets 16

4.4. Effects of Market Power 17

5. Conclusions and Future Outlook **18**

References **19**

Appendix **22**

A1. Example of Representative Manufacturer Overcompliance 22

A2. Conceptual Framework for Analyzing the Effects of Overlapping NHTSA and EPA Rules 23

Both Firms Complying under the NHTSA Rules that Allow Payment of the Fine 23

Result When Both Firms Must Comply with Both Regulations 24

A3. Effects of Other Regulations: Zero Emission Vehicle Regulations in California and Participating States 24

1. Introduction

In the absence of a US national cap-and-trade market for greenhouse gas (GHG) emissions, industry and regional market-based policies are becoming increasingly important for achieving cost-effective carbon reduction and energy efficiency improvements (Burtraw et al. 2014). In the transportation sector, such market-based mechanisms have not been easy to implement because of the large number of sources and the challenge of measuring energy use or emissions from individual vehicles. However, recent changes to the joint Corporate Average Fuel Economy (CAFE) regulations for light-duty vehicles present new opportunities for credit trading, which could lower the costs of meeting the more stringent standards.

US fuel economy standards were constant for many years. However, under the new rules, implemented jointly by the National Highway Traffic Safety Administration (NHTSA) and the US Environmental Protection Agency (EPA), manufacturers face increasingly strict limits are on both fuel use and GHG emissions of the vehicles they produce for model years 2012 through 2025 (EPA.2012). To lower the costs of meeting the new standards, the new rules allow manufacturers the flexibility to bank, borrow and trade credits.

Although the standards have been set jointly by the two agencies, in practice, there are differences in how the standards can be met, including different credit programs and rules on trading. As we see below, restrictions in one program are likely to affect compliance strategies in the other program and to decrease the efficiency of meeting the programs' common goals of reducing fuel use and emissions.

This article examines the design and efficiency of the credit trading programs established as part of the new CAFE and GHG rules. We evaluate the efficiency of different provisions of the credit trading programs by comparing the expected costs and benefits of the standards to the costs and benefits in an ideal setting, where manufacturers have perfect information and no market power, and the credit trading programs have no distortions.

We begin with a detailed description of the new CAFE and GHG credit regulations, including summarizing how credits are defined and traded in the two markets, and identifying key similarities and differences between them. We then examine available evidence about these markets during the early years of the programs from 2012 to 2015, including information on trends in banking, in credit prices, and the amount of credit trading over time, to give a sense of how well the markets are working. This is followed by an assessment of both credit programs and the emerging markets for trading credits between manufacturers. We discuss the major factors that may prevent these markets from improving the efficiency of the standards, drawing on lessons from the literature about previous pollution trading programs. We present conclusions and the outlook for the future in the final section.

2. Background and Overview of the New CAFE and GHG Credit Markets

Manufacturers must comply with both the NHTSA and EPA rules, with each rule having its own credit program and market. Although the two agencies intended to harmonize the stringency of the rules, they are not the same because the provisions of the two credit programs are different. Here we first show the standards and then describe some of the key differences in the credit programs.

2.1. The CAFE and GHG Standards

NHTSA sets CAFE standards requiring that each manufacturer's vehicle fleet achieve a minimum average miles per gallon (mpg). Cars and light trucks have separate standards, with trucks facing lower sales-weighted average fuel efficiency requirements than cars. In 2008, NHTSA was required under the Energy Independence and Security Act (EISA) to set annual standards for vehicle fuel efficiency at “maximum feasible” levels through 20301. At about the same time, EPA was given authority under the Clean Air Act (CAA) to regulate GHG emissions from vehicles as a pollutant.2 Because of the direct relationship between a vehicle’s gasoline consumption and its CO2 tailpipe emissions,3 these two regulations are closely related.

Although NHTSA and EPA have collaborated in a joint rulemaking to reduce fuel and GHG emissions from the light duty fleet, the agencies have separate legal mandates that they are required to meet (i.e., under the EISA and CAA, respectively), and automakers must meet separate standards for fuel economy and GHG emissions.4 Figure 1 shows the changes over time in both the NHTSA CAFE standards (left axis) and the EPA GHG standards (right axis), with the new standards, beginning with model year 2012, shown as dashed lines. By the 2025 model year, fuel consumption and GHG emissions are projected to fall by about half as a result of the stricter CAFE and GHG standards, respectively.

2.2. Flexibility in the Credit Markets

For a program to be economically efficient, it must provide incentives for manufacturers to increase fuel economy and reduce GHG emissions in the least costly way—for each manufacturer and across manufacturers—and over time. Under both programs, manufacturers earn credits whenever they overcomply with the standard during a compliance period. In principle**,** both rules for the 2012–25 model years provide manufacturers with three options for flexibility to lower the costs of meeting the standards.

First, manufacturers can use credits from overcompliance in one fleet (e.g., cars) to achieve compliance in the other fleet (e.g., trucks). This is often referred to as averaging, and it is likely to lower costs, especially for manufacturers whose marginal costs differ across their car and truck fleets. Second, manufacturers can bank credits from overcompliance in one year to use for compliance in a future model year. These banked credits can be held and used for up to five years into the future, or used to cover shortfalls in the previous three years. These banking provisions help firms to smooth and therefore lower the cost of complying with increasingly strict regulations over time (Ellerman et al. 2005).

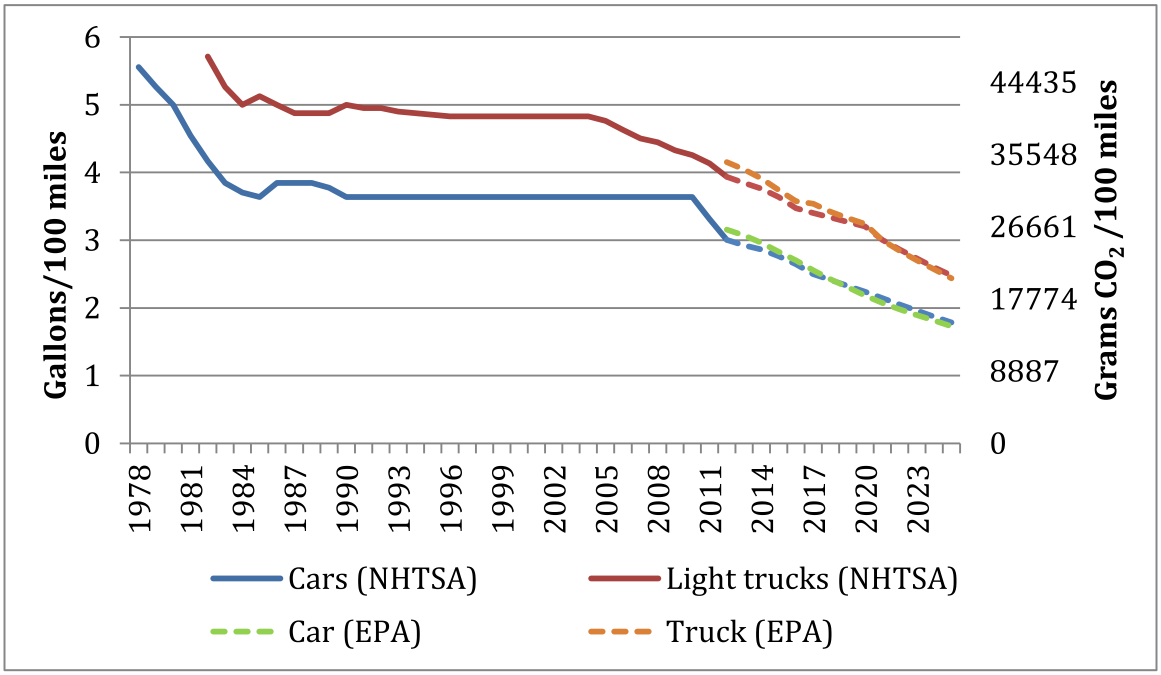
[1] See https://www.gpo.gov/fdsys/pkg/USCODE-2011-title49/pdf/USCODE-2011-title49-subtitleVI-partC-chap329-sec32902.pdf

[2] The US Supreme Court case was *Massachusetts v. Environmental Protection Agency*, 549 US 497 (2007).

[3] One gallon of gasoline contains 8.887 grams, or 0.008887 megagrams (Mg), of CO_2.

[4] 77 Fed. Reg. 62623 (Oct. 15, 2012).

FIGURE 1. CAFE AND GHG STANDARDS (GALLONS PER 100 MILES), AND EPA GHG STANDARDS (GRAMS CO_2 PER 100 MILES)



Notes: The NHTSA fuel economy standards are presented in gallons per mile for so they can be compared to the EPA GHG emission standards. The new joint standards started in 2012. Differences between the standards from 2012 to 2025 are due to differences in nontailpipe emissions, which EPA accounts for but NHTSA does not.
Sources: McConnell (2013); grams of CO_2 per mile forecasts from www.epa.gov/oms/climate/documents/420f12051.pdf

Third, for the first time, manufacturers can buy and sell credits among one another. This will lower the overall costs of reducing emissions and fuel use because it will encourage manufacturers with low costs to exceed the standards and sell earned credits to manufacturers that are below the standard (Montgomery 1972). The potential for savings depends on the heterogeneity of costs across companies (Newell and Stavins 2003) and how well credit markets function (Stavins 1995). Analyses of the earlier CAFE standards found that the standards resulted in significant variation in the marginal costs of reducing fuel economy across manufacturers,[5] suggesting that credit trading across firms could achieve substantial cost savings.

2.3. Differences in how Credits are Defined

In both the NHTSA and EPA programs, credits are granted to manufacturers each year based on the extent to which their vehicles do

5 For example, Jacobsen (2013) estimates that the marginal cost of increasing CAFE standards by one mile per gallon ranges from $0 (for unconstrained firms) to $438 per vehicle. Anderson and Sallee (2011) also find substantial variation in marginal costs of increasing the standards, although they find a much smaller variation.

better than the standards. Credit units are defined differently in the two programs.[6]

2.3.1. Definition of Credits in the NHTSA Program

Under NHTSA's CAFE program, a credit is earned for each one-tenth of a mile per gallon that each vehicle exceeds its miles per gallon standard. A manufacturer's total credits earned in a given period, therefore, are calculated as the product of 10 times the difference between the average fuel economy across its fleet and the fuel economy standard for its fleet.[7] Credit units are thus based on an emissions rate, and do not reflect how much fuel is actually saved given that vehicles are above the standard. Because vehicles are driven different miles over time, the amount of fuel reduced from the credits will differ depending on the mix of vehicles sold.

NHTSA makes the simplifying assumption that each car and each truck is driven the same number of miles over its lifetime (195,264 miles for cars and 225,000 miles for trucks). However, this assumption fails to account for differences in miles driven and the lifetime of vehicles within the car and truck category, which means the crediting system will tend to overcredit some vehicles and undercredit others. This is a potentially important source of inefficiency (Jacobsen et al. 2016).

In addition, because NHTSA credits are specified in rates (mpg), they cannot be traded one for one across car and truck fleets, either within a firm, or across firms. They must first be adjusted to account for the differences between car and truck miles driven. This way of designating credits seems to add unnecessarily complexity to potential markets for trading.

2.3.2. Definition of Credits in the EPA Program

The EPA program defines credits in terms of emissions reduced relative to the emissions allowed by the standard. To determine emissions, manufacturers much first convert emissions rates (in grams of CO_2 per mile) total emissions over the lifetime of their vehicles. They do this by using the same assumptions on total lifetime miles for cars and trucks as NHTSA (see above). Credits are then denoted in terms of the megagrams (Mg) of CO_2—i.e., the mass of CO_2—saved relative to the standard. As with the NHTSA rules, the simplifying assumption that all vehicles in a fleet are driven the same number of miles is a source of inefficiency.[8] But, because EPA credits are defined in terms of emissions saved, they have the advantage of being more directly tradable across car and truck fleets and between different manufacturers.

2.4. Differences in Banking Provisions

Although both programs allow banking, they impose different expiration dates on earned credits (see Table 1). In a setting where each manufacturer's compliance requirement is binding, these expiration dates lower the efficiency of the programs because expiration dates reduce manufacturers' incentives to

---

6 See Appendix A1 for an example of a representative manufacturer that earns credits under both programs during a compliance period.

7 NHTSA requires manufacturers to use a sales-weighted harmonic average of their fleets to calculate the average mpg.

8 A more efficient policy would give vehicle driver incentives to reduce fuel use and emissions whether by the type of car she drives, or the number of miles driven. This implies a different regulatory approach than CAFE, such as a gasoline or carbon tax.

smooth their abatement over time. As we discuss later, however, placing limits on how long credits last also protects the programs from the potential problem that the standards may not produce "additional" reductions for those manufacturers whose emissions or fuel use would have been less than the standards in any case. When banking is allowed for these firms' aggregate emissions and fuel use reductions from the rules will be lower than expected. Whether the banking expiration dates improve or reduce efficiency depends on the relative magnitudes of these two effects.

2.5. Differences in Emissions Averaging Between Car and Truck Fleets

The EPA rules provide more flexibility for manufacturers to average emissions between their car and truck fleets (see fourth row of Table 1), but there are differences in what the two agencies allow. EPA does not limit averaging within a manufacturer's own fleet, whereas the NHTSA rules limit how many credits can be transferred between a manufacturer's car and truck fleets. It is not clear why NHTSA limits these transfers, but the reduction in flexibility raises costs to the manufacturers of meeting the NHTSA standards if the car and truck standards are binding. And, the NHTSA limit on transfers also raises the costs of compliance with the more flexible EPA rules because manufacturers must comply with both rules.

2.6. Penalties for Noncompliance

Another key difference between the two programs is the penalty for noncompliance. Under NHTSA rules, manufacturers have always been allowed to pay penalties if they cannot meet the standard. If the rules turn out to be more expensive than anticipated or fall more heavily on some firms than others, the fine limits the cost of additional reductions. Under the EPA regulations, which are governed by the CAA, no fee in lieu of compliance is allowed. That is, if a manufacturer is found to be noncompliant, a decision about whether that manufacturer may sell vehicles and under what penalty would have to be negotiated on a case-by-case basis. If the noncompliance penalty under the EPA program exceeds the NHTSA fine, and the stringency of the standards is equivalent, then the NHTSA fine becomes irrelevant.[9] In a world with no uncertainty, removing any fines increases the efficiency of the programs, assuming firms can freely trade. But when demand and costs are uncertain, setting a fine or a bound on marginal costs can improve efficiency.[10] We discuss this issue in more detail below.

2.7. Credits for Alternative Fuel Vehicles

Another difference between the two programs concerns how credits are granted for alternative fuel vehicles, such as plug-in electric and all-electric vehicles. NHTSA grants no credits for these vehicles, whereas EPA has several provisions designed to increase the volume of electric vehicles. Manufacturers are allowed to count vehicles that run on electricity as having zero emissions of CO_2. However, actual CO_2 emissions from these vehicles depend on how the electricity that powers them is generated. Most studies of this issue have found that levels of CO_2 emissions vary significantly depending on where the power is generated (Holland et al 2015), but in most regions

[9] We discuss the issue of overlapping regulations in more detail later. Appendix A2 which can be found here (link) presents a graphical illustration of this issue.

[10] Pizer (2002) presents this result using a general model of GHG abatement with uncertain benefits and costs.

emissions are not zero under the current power infrastructure and regulatory requirements. Too many credits from electric vehicles are being generated, which reduces the stringency of the standards.

Another provision of the EPA rules is that beginning with the 2017 model year, a manufacturer is allowed to count each electric vehicle as being equivalent to more than one vehicle for the purposes of calculating its total credits. This so-called "credit multiplier" provides too many credits for electric vehicles and raises the cost of meeting the standards. It is also likely to increase emissions overall as the non-electric fleet will have to reduce less and the emissions of the electrics is counted as having zero emissions.

TABLE 1. COMPARISON OF CREDIT PROVISIONS UNDER NHTSA AND EPA PROGRAMS

Regulation	NHTSA CAFE program	EPA GHG program
Definition of a credit	1/10 mpg above manufacturer's required mpg standard for fleet	1 Mg of CO_2 below the manufacturer's required standard*
Credit banking (carry forward)	5-year banking period	From 2009 to 2011, companies banked credits through the Early Crediting Program; 5-year banking period, with the exception that credits earned between 2010 and 2016 can be carried forward through 2021
Credit borrowing (carry back)	3-year carry back period	3-year carry back period
Limits on manufacturers' credit transfers between car and truck fleets	Limits on credits that can be transferred between cars and trucks: MY 2011–2013, 1.0 mpg MY 2014–2017, 1.5 mpg MY 2018 on, 2.0 mpg	No limits on transfers between cars and trucks in each manufacturer's fleet
Monetary cost of noncompliance	Fee up until July, 2016 $5.50/tenth mile over standard, per vehicle; starting July, 2016, $14/tenth mile over standard	Unknown penalty, but could be as high as $37,500 per car for violation of the CAA
Provisions for alternative fuel vehicles	Credits for ethanol and methanol in fuels are being reduced. Electric, hybrid electric, or fuel cell vehicles are treated the same as conventional vehicles.	Allows manufacturers to count each alternative fuel vehicle as more than a single vehicle. Multipliers range from 2.0 to 1.3, depending on the extent of alternative fuel used and the MY. Emissions from battery electric vehicles assumed to be zero.
Exemptions	No exemptions for manufacturers with limited product lines; fines can be paid	Temporary Lead-time Allowance Alternative Standards (TLAAS) for manufacturers with limited product lines through 2015

*Vehicle and fleet average compliance for EPA's GHG program is based on a combination of CO_2, hydrocarbons, and carbon monoxide emissions which are the carbon containing exhaust constituents. These GHG emissions are referred to here as CO_2 emissions for shorthand.

EPA argues, however, that the overall long-run efficiency of the rules will be enhanced by the alternative vehicles policy. This is because the more rapid introduction of alternative fuel vehicles will result in knowledge spillovers and industry-wide cost reductions. This long-run effect remains to be seen, but in the short-run, the policy will grant too many credits for electrics, drive up the cost of meeting the regulations, and reduce the stringency of the standards.

2.8. Standards for Small Volume Producers

Yet another difference between the two programs is that to address distributional concerns, the EPA program provides less stringent standards for small-volume producers—known as Temporary Lead-time Allowance Alternative Standards—while the NHTSA does not (see bottom of Table 1). These lower standards may be efficient because they allow small-volume manufacturers with very limited and specialized product lines and high costs to continue producing, at least in the short term.

3. Empirical Evidence on Market Outcomes

The evidence to date suggests that automakers are using the new credit banking and trading mechanisms in the CAFE and EPA GHG programs to reduce their compliance costs under both rules. Although the available data do not allow us to determine the exact number of credits that have been transferred between car and truck fleets, we are able to conclude that such transfers have been occurring. In addition, we observe significant banking behavior, as companies are overcomplying with current standards, either because the standards are not binding on some manufacturers or because they anticipate using the banked credits in later years when standards become more stringent. Finally, over the last several years, through 2015, there has been some trading of credits between manufacturers, and the volume appears to be increasing over time.[11] We show evidence of these trades, discuss trends in trading over time, and provide some information about prices paid for credits in these trades.

3.1. Credit Transfers between Cars and Trucks

Table 2 shows net credits earned in the EPA GHG program, and total GHG emissions separately for cars and trucks across all manufacturers for each year. [12] Because net credits earned are positive in each year, the industry as a whole has been in compliance with the EPA standard, but by only a small amount: total industry-wide emissions were less than 1 percent lower than required between 2012 and 2014. Table 2 also shows that in the first several years of the EPA GHG program, manufacturers earned more credits from their passenger car fleets than from their light-duty truck fleets.

[11] Because EPA makes more data publicly available than NHTSA, including actual credit trades, we report EPA compliance information. However, neither agency reports information on the price of trades.

[12] NHTSA does not report data on credits earned by manufacturer. Although it does report NHTSA credits held in any period, it is not always possible to infer how many were earned in a given year (see NHTSA (2014).

TABLE 2. EPA GHG NET CREDITS AND TOTAL EMISSIONS, BY MODEL YEAR

Model year	Passenger vehicles		Light trucks	
	Net credits (million Mg)	Total emissions (million Mg)	Net credits (million Mg)	Total emissions (million Mg)
2009*	57.91	1,600.69	40.16	1,247.43
2010*	50.54	1,716.27	45.16	1,666.98
2011*	8.29	1,676.92	28.73	1,934.53
2012	29.57	2,204.51	0.67	1,699.37
2013	37.80	2,402.95	0.99	1,888.27
2014	28.86	2,258.11	11.43	2,113.08

Notes: Net credits are defined as the sum of credits earned (i.e., overcompliance) minus deficits (i.e., undercompliance). Both credits earned and total emissions are calculated over the life of the vehicles produced in a given model year. * denotes an early crediting year.
Source: Author calculations based on EPA (2015b).

In 2012, overcompliance for cars was 29 million Mg of CO_2, which is several orders of magnitude more than the overcompliance for trucks—net credits for trucks were just 0.67 million Mg of CO_2. The general picture is the same for 2013. In the 2014 model year, net credits are still higher for cars, but there is also a significant increase for trucks. Although the banking and borrowing provisions prevent us from using these data to directly determine firm behavior, the data do suggest that in the 2012–14 perioed, it was easier to overcomply for passenger cars than for trucks.

3.2. Banking

Overall, the data show that manufacturers accumulated credits in the early years of the program. Between the 2009 and 2011 model years, both NHTSA and EPA allowed early banking of credits in advance of the tightening of the standards in 2012. NHTSA had allowed banking in the CAFE program leading up to the new rules, and EPA also wanted to provide flexibility to manufacturers to meet the standards because compliance is likely to be lumpy, due to the fact that vehicles are redesigned roughly every four to seven years (Blonigen et al. 2013). Manufacturers as a whole have continued to accumulate credits since the regulations took effect in 2012. Total EPA credit holdings at the end of 2011 were about 226 million Mg and they were 285 million Mg by the end of 2015. We estimate that the magnitude of these EPA credit holdings at the end of 2015 would be sufficient to cover about 8-9 percent of the total reductions required by the regulations through 2025.

A substantial amount of early banking is what we would expect with lower costs before the standards begin and increasingly strict standards in the future. Indeed, many automakers argue that the most costly and difficult standards to meet will be those for the 2022–25 model years. This strategy of overcomplying early and using banked credits later is also consistent with observed banking behavior in other emissions trading programs.[13] Although this banking behavior relaxes the effective stringency of future standards, the impact is dampened by the fact

[13] In a study of the US acid rain program, Ellerman and Montero (2007) find that capped firms spent the first five years of the program banking permits before starting to draw down their banked supply of permits for compliance in later years, when the standards were tightened.

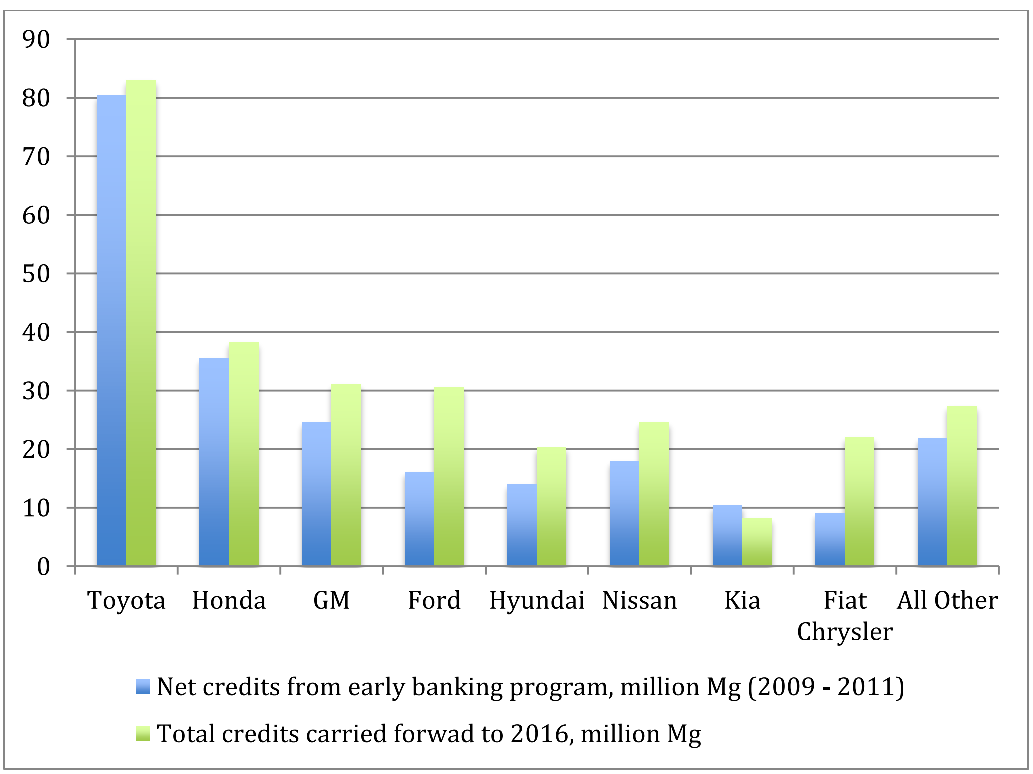
that credits can only be carried forward for five years (see Table 1).

The distribution of banked credits is different across individual automakers, however, with a small subset of manufacturers earning a majority of the credits. For example, between 2009 and 2011, Toyota and Honda banked about 56 percent of the total early GHG credits but sold only about 31 percent of passenger cars and light trucks. The big three US automakers, Ford, GM, and Chrysler, sold about 44 percent of all passenger cars and light trucks during this period but earned only about 23 percent of all GHG credits. The first bar in The first bar in Figure 2 shows credits earned between 2009 and 2011 for many of the manufacturers, and the second bar shows their credit holdings as of the start of 2016. Since 2011, most firms have increased their credit holdings, though for most, the majority of credit holdings were earned from 2009 to 2011, before the new standards came into effect.

3.3. Trading Across Manufacturers

Table 3 presents data on EPA GHG credit trades (shown as credit sales in Mg) that occurred from 2012 to 2015. The first column shows the year of the trade, and the second column shows the vintage of the traded credit. For example, in 2012 Nissan sold 500,000 of their credits earned in 2011 to Chrysler. Because credits expire, after 2021 in the EPA market, we expect credits earned in earlier years to be sold first. All of the credits sold through 2015 were earned between 2010 and 2012, except for those sold by Tesla which, because it sells only electric vehicles, has less incentive than other companies to bank credits for future compliance.

FIGURE 2. EARLY CREDITS AND CREDITS CARRIED FORWARD TO 2016, BY MANUFACTURER, DENOTED IN MILLION MG GHG EMISSIONS



Source: EPA (2016).

The total volume of trades as shown in Table 3 is about 20 million Mgs, which is roughly 7 percent of total credits holdings in 2015. But it is important to note that the market for trades in the first few years, from 2012 to 2013 was very thin: total trades were about 2.6 million Mg credits which was just over 1 percent of total credits earned by the end of 2013. However, the volume of trades was close to three times higher in 2014 than in the previous two years, at 7.2 million Mg. Then volume increased again in 2015 by about 4 million Mgs. Further, some of the largest companies, including Toyota and GM, have just recently made single trades for the first time.

Trading activity may increase in the future, both because banked credits will expire and both the car and truck standards will continue to increase in stringency, making it more difficult for some companies to rely solely on averaging their car and truck fleet credits or using banked credits to meet each standard. In summary, the volume of trades is growing and is likely to continue to do so as the standards tighten.

TABLE 3. EPA GHG CREDIT TRADES THROUGH 2015

Transaction Year	*Credit Vintage*	*Buyer*	*Seller*	*Credit Sales (Mg)*	*Sales Per Year (Mg)*
2012	2011	FCA/Chrysler	Nissan	500,000	1,067,713
2012	2010	Ferrari	Honda	90,000	
2012	2010	Mercedes-Benz	Tesla	35,580	
2012	2011	Mercedes-Benz	Tesla	14,192	
2012	2012	Mercedes-Benz	Tesla	177,941	
2012	2012	Mercedes-Benz	Nissan	250,000	
2013	2010	FCA/Chrysler	Honda	144,383	1,593,072
2013	2013	FCA/Chrysler	Tesla	1,048,689	
2013	2010	Mercedes-Benz	Nissan	200,000	
2013	2010	Mercedes-Benz	Honda	200,000	
2014	2011	Mercedes-Benz	Nissan	500,000	7,201,602
2014	2014	FCA/Chrysler	Tesla	1,019,602	
2014	2010	FCA/Chrysler	Toyota	2,507,000	
2014	2010	FCA/Chrysler	Honda	3,000,000	
2014	2010	Ferrari	Honda	175,000	
2015	2015	FCA/Chrysler	Tesla	1,337,853	11,215,577
2015	2014	FCA/Chrysler	Tesla	694	
2015	2013	FCA/Chrysler	Tesla	695	
2015	2010	FCA/Chrysler	Honda	5,680,851	
2015	2012	GM	Coda	5,524	
2015	2013	GM	Coda	1,727	
2015	2014	Jaguar Land Rover	Toyota	831,358	
2015	2011	Jaguar Land Rover	Nissan	39,063	
2015	2013	Mercedes-Benz	Nissan	1,000,000	
2015	2011	Mercedes-Benz	Nissan	314,192	
2015	2011	McLaren	Nissan	3,620	
2015	2010	BMW	Honda	2,000,000	

Sources: Author calculations based on the Greenhouse Gas Emission Standards for Light-Duty Vehicles 2012, 2013, 2014, and 2015 Reports.

3.4. Information on Credit Prices

Information about the prices paid for credits is important for several reasons. Price information helps potential market participants to make profit-maximizing decisions. If manufacturers cannot identify the typical market price for a GHG credit, it will be more costly for them to decide whether to hold or sell credits.[14] Credit prices also reveal information about marginal costs, which is useful for estimating the overall costs of the standards. In a competitive market for credits, the marginal credit price would equal the equilibrium marginal cost of meeting the standard. However, transaction prices may not reflect marginal costs if multiple regulations overlap, markets are thin, or other market distortions exist.

Neither NHTSA nor EPA requires manufacturers to report credit prices. [15] Thus, there is virtually no public information available about transactions prices. In order to shed light on these prices, we identify two approaches for calculating transaction prices based on the data that are currently publicly available. Because public data for calculating NHTSA prices are not available, we calculate prices in the EPA GHG credit market and then convert them into equivalent NHTSA credit prices.

3.4.1. Estimating Prices: Approach 1

Under the first approach, we estimate the credit price by merging trading quantities from EPA (2014a) with revenue data from Tesla Motors' 2013 SEC Filing Form 10-K to compute 2012 and 2013 EPA GHG credit prices. In 2013, Tesla sold $64.6 million worth of EPA GHG credits, which is equal to $63.7 million denominated in 2012$ (see Table 4). By dividing revenue reported from GHG credit sales by the total sales of EPA GHG credits sold by Tesla, we find that Tesla sold each GHG credit for an average of about $36 for 2012 and $63 for 2013 as show in the 5th column of Table 4 (both in 2014$).

3.4.2. Estimating Prices: Approach 2

For the second approach, we use public information from a settlement between two manufacturers and the federal government. More specifically, in November 2014, EPA and the US Department of Justice reached a settlement with Hyundai and Kia concerning violations of the CAA. The initial complaint was filed in response to the companies' sales of about 1.2 million model year 2012 and 2013 cars and SUVs that had labels that overstated the vehicles' fuel economy. The settlement required both companies to forgo 4.75 million EPA GHG credits in 2014, which EPA "estimated to be worth over $200 million" (EPA 2014b). If we assume that these credits are worth exactly $200 million in 2014$, or $193.97 million in 2012$, and divide this by the number of credits (4.75 million), we get a credit price of $40.84/Mg (see Table 4).

Based on assumptions about the CO_2 content of a gallon of gasoline, mileage for cars, and a baseline level of fuel economy, we convert the EPA GHG credit prices to equivalent NHTSA credit prices and obtain a 2012 NHTSA credit price of $67.76 per mile per gallon per vehicle, and a 2013 price of $115.67 (see Table 4). These values are higher than the NHTSA fine of $55 per mile per gallon per vehicle during this time period, which implies that the EPA rules are more binding on manufacturers during this period than the NHTSA rules.

[14] The costs of finding suitable trading partners are higher in thin markets, especially in the absence of a centralized trading system (Klier et al. 1997).

[15] Both agencies require manufacturers to report credit holdings and credit trades for compliance purposes only.

TABLE 4. CALCULATING CREDIT PRICES (2014$)

Year	Action	Value (million 2014$)	Quantity (million Mg)	EPA GHG price ($/Mg)	Equivalent NHTSA credit price ($/ mpg/vehicle)
2012	Tesla sales of EPA GHG credits	8.4	0.228	36	70
2013	Tesla sales of EPA GHG credits	65.7	1.049	63	119
2014	Hyundai and Kia CAA settlement	200	4.750	42	80

Notes: To convert the price of an EPA GHG credit to 10 NHTSA credits (1 NHTSA credit is 1/10 of an mpg), we assume that: increasing mpg by 1 from 30 to 31 is equivalent to reducing gallons per mile by 0.0011; each gallon of gasoline contains 0.008887 Mg of CO_2; and cars are driven 195,264 miles over their lifetime.
Sources: Tesla Motors' 2013 SEC Filing Form 10-K; EPA (2014a, table 4-1; 2015a, table 4-1;2014b).

4. Assessment of the Credit Trading Markets and Lessons From Other Pollution Regulations

Despite the opportunities for lower cost of compliance allowed by the new credit trading markets, there are several issues that may influence how effective these markets will be in practice. In this section we explore four areas that could prevent the credit markets from improving efficiency in achieving the goals of the EPA and NHTSA regulations: overlapping regulations, are emissions, reductions additional, lack of transparency and thin markets, and the effects of market power.

4.1. Overlapping Regulations

One area of increasing concern for the success of emissions trading programs is the issue of overlapping regulations (Burtraw and Shobe 2012; Goulder 2013).[16] The relationship among regulations, both across jurisdictions and over time, is complex and depends on the regulations' timing and design (Levinson 2012; Goulder and Stavins 2012). Because the joint NHTSA and EPA regulations are separate but effectively regulate the same thing (i.e., fuel use and the associated emissions of CO_2),[17] unless they are completely harmonized, they are likely to interact with each other, resulting in higher costs.

[16] Another area of concern is changing regulations. For example, although the SO_2 allowance trading market was successful for a long period, it was later essentially gutted by changes in broader air pollution regulations and the ability of utilities to trade ton for ton across state lines (Schmalensee and Stavins 2013).

[17] The reason for the overlapping regulations of the two programs appears to be legal. Under early legislation, and more recently under the EISA, Congress authorized NHTSA to set fuel economy standards. However, EPA has been authorized under the CAA to set CO_2 standards starting in 2012. Thus, the agencies claim to have separate legal mandates.

Given the differences between the regulations (see table 1), a key impact of their overlap is that navigating compliance under the two programs is more difficult than it would be under a single program. If the programs were fully harmonized but continued to overlap, then compliance under the two programs would be similar to achieving compliance under a single program; manufacturers would simply use the same compliance strategy for both programs. However, given the differences in how credits are defined and how they can be traded within and across manufacturers fleets means manufacturers must have separate compliance strategies for the two programs. This makes it more difficult to achieve an efficient allocation of both fuel economy improvements and GHG abatement.

The overlapping nature of the two programs will make credit trading especially challenging. Under a single trading program, prices reflect the marginal costs of compliance, which helps guide market participants in making efficient investment decisions. However, with multiple, overlapping programs, prices in one credit market may no longer reflect the marginal costs of compliance. For example, the marginal cost of compliance in one program may be close to or equal to zero for a manufacturer that is in compliance under the other program.[18] Rules that create overlapping regulations that are not well harmonized, such as these by EPA and NHTSA, reduce transparency and increase the costs of attaining the joint goals of the two standards.

18 Appendix A2 discusses this issue in more detail using a stylized model. Appendix A3 discusses how the overlap between the Zero Emission Vehicle (ZEV) regulation and the CAFE/EPA regulations influences credit prices and efficiency. These are now going to be online.

4.2. Are Emissions Reductions from the Regulations Additional?

Some automakers have historically exceeded fuel economy standards (EPA, 2014a, 2016). This means that if these companies earn credits for exceeding the standards, these credits do not represent “additional” reductions because the companies would have achieved the reductions without the crediting program. When there are credit markets, the sale and use of credits earned from non-additional behavior effectively loosens the stringency of the standard, which lowers realized fuel economy improvements and GHG reductions.

The problem of additionality has been an issue in other emissions markets, including Phase 1 of the US Acid Rain Program.[19] Montero (1999) finds that many electricity generating units that opted into Phase 1 of the program had business-as-usual (BAU) emissions that were below their permit allocations. Thus they were able to sell the surplus permits to other capped firms, which actually resulted in higher overall emissions. Similar additionality issues have arisen more recently in cap-and-trade programs for CO_2 that have carbon offset programs (Bushnell 2012; Bento et al. 2015).[20]

19 The Acid Rain Program allowed large power plants in the middle and eastern parts of the Untied States to trade emissions for reduction of SO_2 under the Clean Air Act of 1990. During Phase 1 of the program, the regulation allowed a subset of unconstrained electricity generating units to voluntarily be regulated. Owners of these units were then able to earn and sell SO2 permits to other regulated power plants.

20 Carbon offset programs allow owners of unregulated emissions sources, such as dairy farms, to earn carbon credits for reducing emissions below a specified baseline.

4.2.1. Evidence of Additionality

We find some evidence that credits were given for BAU behavior in the early years of the new fuel economy and GHG standards for passenger cars and light trucks. Figures 3a and 3b, which indicate average fuel economy and the CAFE standards from 2000 to 2011 for cars and light trucks, respectively, reveal that passenger car standards remained flat until 2011, when they were changed under the new standards, while light truck standards were flat until 2005 and began to increase in 2006. As shown in Figure 3a, many of the large manufacturers appear to have overcomplied with their passenger car standard, independent of any change in the standard. Toyota, for example, increased its passenger car fleet fuel economy from slightly less than 30 miles per gallon in 1999 to 35 miles per gallon by 2005. Ford and GM also increased their passenger car fleet fuel economy, from slightly under the standard in 1999 to more than 2 miles per gallon over the standard by 2007. As shown in figure 3b, the trends for trucks are similar although not as strong.

One reason for overcompliance in the years leading up to the recent policy changes is the significant increase in real gasoline prices. Between 1999 and 2008, real gasoline prices nearly tripled, from approximately $1.17 to $3.24 (in 2015$). Numerous studies have shown that this gasoline price increase led to consumers demand more fuel efficient vehicles in new and used automobile markets (Li et al. 2009; Busse et al. 2013), which likely resulted in some manufacturers banking credits for BAU behavior. [21]

From 2009 to 2011, before the new standards took effect, most manufacturers continued to produce fleets that have fuel economy levels above the standards, as we can see from Figures 3a and 3b. This was a time when many credits were banked for future use (see section on banking above). To the extent these banked credits were not additional, then total fuel reductions from the standards will be lower than expected. However, the stringency of both standards is scheduled to increase to be far above the historic BAU fuel economies of even the most fuel-efficient fleets, reducing the likelihood that additionality issues will influence program outcomes in the long run. Separating whether banked credits are non-additional or whether they are an efficient investment in longer term compliance requires a detailed model of the new vehicle market and is thus a potential area of future empirical research.

[21] This is consistent with Montero (1999), who found that BAU emissions were falling prior to implementation of the Acid Rain Program because of declining low-sulfur coal prices.

FIGURE 3A. AVERAGE FUEL ECONOMY AND CAFE STANDARDS FOR PASSENGER CAR FLEETS, 1999–2011

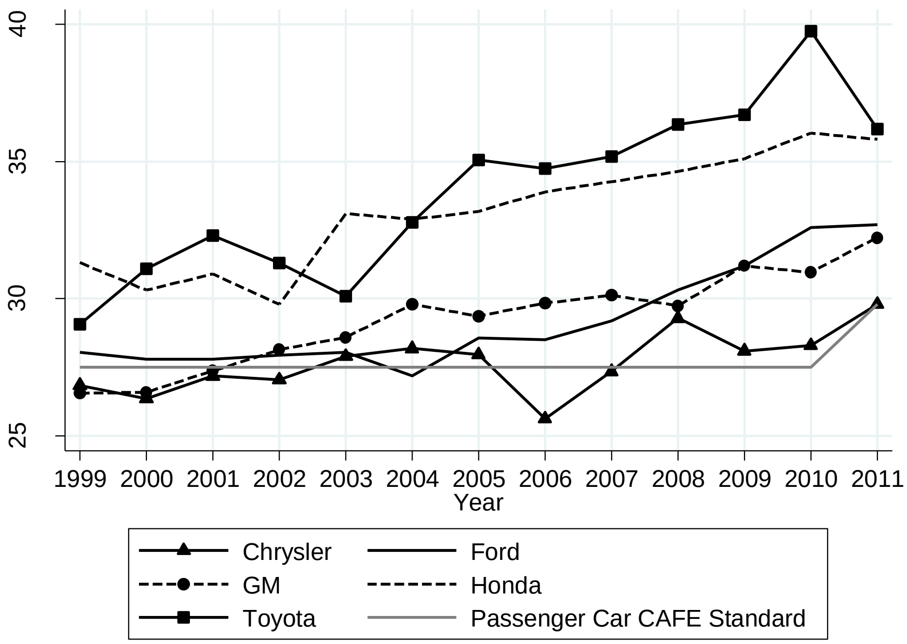
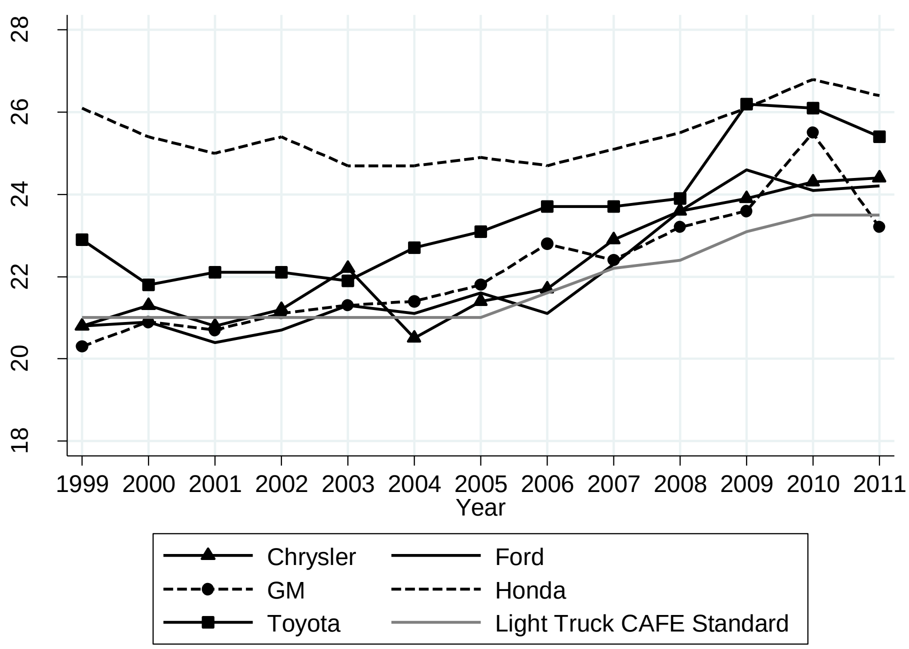


FIGURE 3B. AVERAGE FUEL ECONOMY AND CAFE STANDARDS FOR LIGHT TRUCK FLEETS, 1999–2011



Note: The gray lines indicate the CAFE standards. *Sources for 3a and 3b*: 1999 and 2000 fuel economy data: http://www.nhtsa.gov/cars/rules/CAFE/FuelEconUpdates/2000/index.html; 2001 and 2002 fuel economy data: http://www.nhtsa.gov/cars/rules/CAFE/FuelEconUpdates/2002/index.htm; 2003 and 2004 fuel economy data: http://www.nhtsa.gov/Laws+&+Regulations/CAFE++Fuel+Economy/2004+Automotive+Fuel+Economy+Program; 2005–2011 fuel economy data: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/June_2014_Summary_Report.pdf.

4.3. Lack of Transparency and Thin Markets

A well-functioning market for trading credits between companies requires transparency about the prices of trades that have occurred and a way for potential traders to find each other without incurring high transaction costs (Stavins 1995). The history of credit trading under other vehicle programs such as the California Low-Emission Vehicle and Zero Emission Vehicle programs has been that buyers and sellers of credits find each other on an as-needed basis, and regulators report information on quantities traded but not on prices (CARB, 2016[22]).

The CAFE and EPA credit-trading programs are getting started in a similar way. The limited trading thus far has been done informally, with manufacturers contacting each other directly. EPA reports on quantities traded and who bought and sold credits for each vehicle model year, but not on the price of the trades. NHTSA does not report any information about the credit market. In most auction markets as well as in previous emissions trading programs, the trading price is published and then participants decide whether to buy or sell. Given that parties have to find each other and they do not have information about previous prices, it is not surprising that few trades have taken place.

In addition to the problems of potentially high transactions costs and no price transparency, credit markets have also been thin because of the agencies' midterm review of the standards that is to be finalized in 2018. Uncertainty about the outcome of this review in terms of the longer-term stringency of the standards is likely to make manufacturers reluctant to trade credits until these issues are resolved.

4.3.1. Bounding Credit Market Prices

One potential role for the agencies to encourage more trading is to reduce uncertainty for manufacturers by providing information about the range of possible credit prices. The NHTSA fine for non-compliance[23] already sets an effective price cap on the credit price,, which effectively establishes a "safety valve" on the costs of the regulations. The notion of a safety valve is attributed to Roberts and Spence (1976) and later applied to climate policy by Pizer (2002) and Murray et al. (2009). It involves trading off some confidence about the quantity of pollution reduction that will be attained for more certainty about the cost of the reductions. In this case, if the rules turn out to be more expensive than anticipated or fall more heavily on some firms than others, a fee imposed on the firm in lieu of reductions limits the additional cost and also provides information to manufacturers about the maximum price of a credit. EPA is prohibited from allowing manufacturers to pay a fine, as discussed above, but EPA could sell credits to buyers at a fixed price to set a ceiling on costs.

The agencies could also set a price floor on credits by offering to buy credits at a given price. The combination of the price floor and ceiling would provide certainty to manufacturers about the range of credit prices and would push the market toward greater efficiency. More information would be available to potential participants, and there would be less credit price fluctuation due to likely future shifts in supply and demand (e.g., the development of alternative fuel technologies and changes in gasoline prices).

[22] Information on trades is available at https://www.arb.ca.gov/msprog/zevprog/zevprog.htm

[23] The current NHTSA fine is $140/mpg per vehicle under the manufacturer's standard.

4.4. Effects of Market Power

In a tradable permits market with relatively few firms, as is the case for light-duty vehicles, one issue that arises is whether the market is susceptible to market power. The potential for market power in the CAFE and EPA GHG credit markets depends on the credit balances held by the largest manufacturers. We focus on the EPA GHG program again here because more recent data are available and the EPA and CAFE programs have a similar distribution of credits. Table 5, which ranks the concentration of EPA GHG credits among the six largest companies, suggests that market power may pose a threat to the allocative efficiency of these markets because these six manufacturers own about 80 percent of the credits.

In his analysis of the impact of market power on the efficiency of pollution markets, Hahn (1984) argues that if a few firms have a relatively large number of pollution permits, they will exercise monopoly power by selling relatively few permits, thereby lowering the efficiency gains from trading. The large number of EPA emissions credits held by a few firms as shown in Table 5, and the limited number of trades to date under the EPA program (less than 10 percent of credits have been traded), is consistent with a setting where some firms can act in ways that would restrict competition. However, there is no direct evidence of such strategic behavior and the firms with the largest number of credit holdings have sold some credits over the past few years. Moreover, there are other reasons that companies may be holding credits.

Table 5. Concentration of EPA GHG Credits at the End of the 2015 Compliance Year

(Rank) manufacturer	Credit balance (million Mg)	Market share (%)	Cumulative market share (%)
(1) Toyota	80	29	29
(2) Honda	38	13	42
(3) Ford	31	11	53
(4) GM	31	11	64
(5) Hyundai	20	7	71
(6) Nissan	25	9	80
All other manufacturers	58	20	100
Total	286	100	—

Notes: Credit balances include the sum of car and light truck credits and are net of deficits, penalties, and trades between manufacturers. Manufacturers can use the 2010-15 vintages for compliance up to the 2021 standard.
Source: Author calculations based on EPA (2016).

For example, they may be uncertain about future compliance costs, or they may believe that there could be future changes in the standards. In addition, the trading market is relatively new, and companies are likely to need time to become familiar with the idea of trading credits.[24]

It is also important to note that Hahn's analysis assumes perfect competition in output markets, an assumption that is unlikely to hold in the US automobile market. Rubin et al. (2009) conduct numerical simulations of an imperfectly competitive automobile market to measure the cost savings from incorporating tradable fuel economy standards. They find that market power in the credit trading market between firms lowers the potential cost savings from trading, but only modestly. Overall, we do not find any suggestion that market power is being misused, but it will be important to reexamine this issue as the credit markets become more robust in the future.

5. Conclusions and Future Outlook

This article has looked at two overlapping regulations, one on vehicle fuel use by NHTSA and the other on GHG emissions by EPA, and at how increased flexibility for manufacturers that allows banking and trading can make these regulations more efficient. We focus here on the market for credit trading between auto manufacturing firms, which offers a way for vehicle manufacturers to reduce the costs of attaining increasingly strict standards through the 2025 model year. Our analysis of the credits and credits markets is likely to have implications for other countries that have recently implemented regulations for light-duty fuel consumption, since many of these are including flexible mechanisms for compliance that are similar to those in the United States. The market for credit trading between companies in the United States is at an early stage, and though so far there have been few trades, the number of trades has been increasing rapidly in the last few years. Most manufacturers are in compliance with the standards, and many have used banking provisions to accumulate varying amounts of credits to hold in reserve. It is not clear, at this stage, whether many of the banked reduction credits were additional to what firms would have done anyway, or whether they are needed for spreading the high costs of compliance over time by overcomplying early and undercomplying later. More analysis of this issue is important because the former suggests the standards may be too lax, and the latter suggests that the banking and credit market will be essential to reducing the costs of very stringent standards, especially in the 2022-2025 time period. The combination of these costly standards in the later years and large variation in the ease of compliance between manufacturers suggests an important role for credit trading in the future.

However, we have identified here a number of problems in the structure of the credit markets that may be leading to thin markets with few trades. There is too little information about prices of past trades, and the transactions cost of finding a trading partners can be high. There are ways government can facilitate the market. We suggest that reducing uncertainty about the price of credits, and about the stringency of future regulations will both be important.

Perhaps the greatest barrier to efficient credit trading markets for GHGs and fuel economy is that there are two separate but overlapping rules, with two separate credit markets, each with somewhat different rules about what counts as a credit and how they can be traded. This complicates compliance for the manufacturers and drives up the cost of meeting the joint goals of reducing oil use and GHG emissions. The two rules are governed by two different pieces of legislation, but ideally, they will be more fully harmonized with a single compliance system and credit market.

[24] This possible explanation is consistent with evidence on the efficiency of the first few years of allowance trading under Phase 1 of the Acid Rain Program (Carlson et al. 2000).

References

Anderson, Soren, and Jim Sallee. 2011. Using loopholes to reveal the marginal cost of regulation: The case of fuel-economy standards. *American Economic Review* 101 (4): 1375–1409.

Bento, Antonio, Ravi Kanbur, and Benjamin Leard. 2015. Designing efficient markets for carbon offsets with distributional constraints. *Journal of Environmental Economics and Management* 70 (2): 51–71.

Blonigen, Bruce A., Christopher R. Knittel, and Anson Soderbery. 2013. Keeping it fresh: Strategic product redesigns and welfare. NBER Working Paper No. 18997, NBER, Cambridge, MA.

Burtraw, Dallas, Josh Linn, Karen Palmer, and Anthony Paul. 2014. The costs and consequences of greenhouse gas regulation under the Clean Air Act. *American Economic Review: Papers & Proceedings* 104 (5): 557–62.

Burtraw, Dallas, and William M. Shobe. 2012. Rethinking environmental federalism in a warming world. *Climate Change Economics* 3 (4): 1–33.

Bushnell, James. 2012. The economics of carbon offsets. In *The design and implementation of U.S. climate policy*, ed. Don Fullerton and Catherine Wolfram. Chicago: University of Chicago Press. 197–209.

Busse, Meghan R., Christopher R. Knittel and Florian Zettelmeyer. 2013. Are consumers myopic? Evidence from new and used car purchases." *American Economic Review* 103(1): 220-256.

Carlson, Curtis, Dallas Burtraw, Maureen Cropper, and Karen Palmer. 2000. Sulfur dioxide control by electric utilities: What are the gains from trade? *Journal of Political Economy* 108 (6): 1292–1326.

Ellerman, A. Denny, Paul L. Joskow, Richard Schmalensee, Juan-Pablo Montero, and Elizabeth M. Bailey. 2005. *Markets for clean air: The U.S. Acid Rain Program*. Cambridge, UK: Cambridge University Press.

Ellerman, A. Denny, and Juan-Pablo Montero. 2007. The efficiency and robustness of allowance banking in the U.S. Acid Rain Program. *Energy Journal* 28 (4): 47–71.

EPA. 2012. EPA/NHTSA Joint Rulemaking to Establish Light-duty Vehicle GHG Emissions Standards and CAFE Standards for Model Year 2017 and Later

https://www.regulations.gov/docket?D=EPA-HQ-OAR-2010-0799.

EPA. 2013. Greenhouse gas emission standards for light-duty automobiles: Status of early credit program for model years 2009–2011. https://www.autonews.com/assets/PDF/CA8786048.PDF.

———. 2014a. Greenhouse gas emission standards for light-duty vehicles: Manufacturer performance report for the 2012 model year. http://www.eenews.net/assets/2014/04/25/document_gw_06.pdf.

———. 2014b. United States reaches settlement with Hyundai and Kia in historic greenhouse gas enforcement case. https://yosemite.epa.gov/opa/admpress.nsf/0/15519081FBF4002285257D8500477615.

———. 2015a. Greenhouse gas emission standards for light-duty vehicles: Manufacturer performance report for the 2013 model year. https://www3.epa.gov/otaq/climate/documents/420r15008a.pdf.

———. 2015b. Greenhouse gas emission standards for light-duty vehicles: Manufacturer performance report for the 2014 model year. EPA-420-R-15-026. http://www.epa.gov/otaq/climate/documents/420r15026.pdf.

_______ 2016. Greenhouse gas emission standards for light-duty vehicles: Manufacturer performance report for the 2015 model year. EPA-420-R-16-014. Novemeber. https://www.epa.gov/sites/production/files/2016-11/documents/420r16014.pdf

Goulder, Lawrence H. 2013. Markets for pollution allowances: What are the (new) lessons? *Journal of Economic Perspectives* 27 (1): 87–102.

Goulder, Lawrence H., and Robert N. Stavins. 2012. Interactions between state and federal climate change policies. In *The design and implementation of U.S. climate policy*, ed. Don Fullerton and Catherine Wolfram. Chicago: University of Chicago Press. 109–21.

Hahn, Robert W. 1984. Market Power and Transferable Property Rights. *The Quarterly Journal of Economics* 99 (4): 753-765.

Holland, Stephen P, Erin T. Mansur, Nicholas Z. Muller and Andrew J. Yates. 2016. "Are There Environmental Benefits from Driving Electric Vehicles? The Importance of Local Factors." *American Economic Review*, 106(12): 3700-3729..

Jacobsen, Mark. 2013. Evaluating U.S. fuel economy standards in a model with producer and household heterogeneity. *American Economic Journal: Economic Policy* 5 (2): 148–87.

Jacobsen, Mark, Christopher Knittel, James Sallee, and Arthur van Bentham. 2016. Sufficient statistics for imperfect externality correcting policies. NBER Working Paper No. 22063, NBER, Cambridge, MA.

Klier, T., Rick Mattoon, and Michael A. Prager. 1997. What can the Midwest learn from California about emissions trading? *Chicago Fed Letter*, no. 120, August.

Levinson, Arik. 2012. Comment on "Interactions between state and federal climate change policies." In *The design and implementation of U.S. climate policy*, ed. Don Fullerton and Catherine Wolfram. Chicago: University of Chicago Press. 122–25.

Li, Shanjun, Christopher Timmins and Roger H. von Haefen. 2009. How do gasoline prices affect fuel economy? *American Economic Journal: Economic Policy* 1 (2): 113-137.

McConnell, Virginia. 2013. The new CAFE standards: Are they enough on their own? RFF Discussion Paper 13-14. Resources for the Future, Washington, DC. http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=22180.

Montero, J. P. 1999. Voluntary compliance with market-based environmental policy: Evidence from the U.S. Acid Rain Program. *Journal of Political Economy* 107 (5): 998–1033.

Montgomery, W. D. 1972. Markets in licenses and efficient pollution control programs. *Journal of Economic Theory* 5: 395-418.

Murray, B., R. G. Newell, and W. A. Pizer. 2009. Balancing cost and emissions certainty: An allowance reserve for cap-and-trade. *Review of Environmental Economics and Policy, Symposium: Alternative U.S. Climate Policy Instruments* 3 (1): 84–103.

National Highway Transportation and Safety Administration (NHTSA). 2014. CAFE credit status 2008–2011. http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE_credit_status.

Newell, R. G., and Robert N. Stavins. 2003. Cost heterogeneity and the potential savings from market-based policies. *Journal of Regulatory Economics* 23 (1): 43–59.

Pizer, William. 2002. Combining price and quantity controls to mitigate global climate change. *Journal of Public Economics* 85 (2): 409–34.

Rubin, J., P. Leiby, and David L. Greene. 2009. Tradable fuel economy credits: Competition and oligopoly. *Journal of Environmental Economics and Management* (58): 315–28.

Schmalensee, Richard, and Robert N. Stavins. 2013. The SO_2 Allowance Trading Program: The ironic history of a grand policy experiment. *Journal of Economic Perspectives* 27 (1): 103–22.

Stavins, Robert N. 1995. Transaction costs and tradeable permits. *Journal of Environmental Economics and Management* 29 (2): 133–48.

Appendix

A1. Example of Representative Manufacturer Overcompliance

In this Appendix we illustrate how manufacturers comply with both the NHTSA gallons per mile standards and the EPA GHG standards., Table A1 presents an example of a representative manufacturer that overcomplies with both standards during a given model year. As shown in the left panel, which presents information on credits earned under NHTSA's CAFE program, the manufacturer overcomplies by 1.2 to 1.5 mpg among its car and truck fleets, respectively, earning 1,200,000 car credits and 1,350,000 truck credits. The right panel, which provides example data on the manufacturer's earned EPA credits, indicates that the manufacturer also overcomplies under the EPA program.

TABLE A1. CREDITS EARNED BY A REPRESENTATIVE MANUFACTURER DURING A GIVEN MODEL YEAR

CAFE program			EPA program		
	Car fleet	**Truck fleet**		**Car fleet**	**Truck fleet**
Vehicles sold	100,000	90,000	Vehicles sold	100,000	90,000
Fleet average (miles/gallon)	30.2	25	Average (grams of CO_2/mile)	294.3	355.5
CAFE requirement (average miles per gallon)	29	23.5	EPA GHG requirement (grams CO_2/mile)	306.4	378.2
Difference (average miles/gallon)	1.2	1.5	Difference	12.1	22.7
Credits earned (10* miles/gallon* no. of vehicles)	1,200,000	1,350,000	Credits earned over vehicle lifetime (Mg of CO_2)	236,270	461,440

Notes: Credits are in miles per gallon saved on average for the fleet, not total fuel saved over the vehicles' lifetimes. To convert car credits to truck credits, for example, NHTSA requires that these estimates first be converted to total fuel use and then traded. In other words, under the NHTSA crediting system, car and truck credits do not trade one for one. Cars and trucks are assumed to travel 195,264 miles and 225,865 miles, respectively, over their lifetimes. EPA credits are designated in terms of Mg saved over vehicle lifetimes. Therefore, credits can be traded between car and truck fleets. The EPA and NHTSA make the same assumptions about total miles traveled.

A2. Conceptual Framework for Analyzing the Effects of Overlapping NHTSA and EPA Rules

To illustrate the effects of the overlapping NHTSA and EPA rules on the credit markets, we present a simplified example of two representative manufacturers with different marginal costs of compliance.[25] Figure A1 presents these manufacturers and their costs of complying over the next few years. Each manufacturer is subject to two rules, one from NHTSA to increase the miles per gallon (mpg) of its fleet of vehicles, and one from EPA to reduce megagrams (Mg) of CO_2 (or metric tons of CO_2). If the requirements under the two rules are fully harmonized, we can show the marginal cost of the requirements in terms of either CO_2 reductions or improvements in mpg. One is a linear function of the other. We show the marginal costs in Figure A1 in terms of reduced Mg of CO_2, but we use the figure to talk about both rules.

Each manufacturer is subject to a different target or standard, depending on the fleet of vehicles it produces under the two regulations. Firm 1 represents a large-volume manufacturer that has midrange GHG emissions initially but has relatively low costs of reducing emissions from its fleet (MC_1). Firm 2 has smaller production volumes but higher average initial emissions from its fleet and higher costs of reducing emissions (MC_2), representing, for example, a European manufacturer.

Starting at point A and moving from left to right, the horizontal axis measures Mg of CO_2 reduced by Firm 1 over and above BAU reductions (at the left origin). Starting at point M and moving from right to left, the horizontal axis measures Mg of CO_2 reduced by Firm 2, where the origin (at point M) represents BAU reductions. Both vertical axes measure the marginal cost of reducing one Mg of CO_2 beyond BAU levels. The figure also shows the emissions reduction target that each firm must meet, indicated by the vertical black line representing reductions equal to Mg_T. This target or standard could be different for each firm, depending on the sizes and types of vehicles each firm sells.

Both Firms Complying under the NHTSA Rules that Allow Payment of the Fine

We start with the effect of the NHTSA requirements because they have been in place the longest, and firms have been able to pay a fine in lieu of compliance. To attain this NHTSA standard, the cost for Firm 1 is shown by AFD, and the cost for Firm 2 to attain its standard is MDH. The new NHTSA rules allow firms to trade credits, but they also allow payment of the fine. The NHTSA fine for an automaker is currently $14.00 per 1/10 mpg, or $140 per mpg per vehicle over the standard.[26] Since figure A1 is in terms of Mg of CO_2, we show the fine as f_N, which is either $140/mpg or $61/Mg of CO_2.[27] In this case, both firms would pay the fine rather than comply with the standard. Firm 1 would reduce to $Mg_{1,N}$ or to an average fleet mpg that is below the standard, with costs of ACB; Firm 2 would reduce to $Mg_{2,N}$, with costs of MKL, which is also below the standard. Firm 1 would pay BCED in fines to NHTSA, and Firm 2 would pay KDEL in fines. In this case, even when trading is allowed, no trading in the credit market would occur. Here the fine

[25] Our analysis abstracts from dynamic effects, such as the impact of the regulations on technological advances or on the future stringency of CAFE standards.

[26] The NHTSA fine had been $5.50 per 1/10th mpg or $55 per mpg for many years. It was changed by NHTSA to $14 per 1/10th mpg in July of 2016.

[27] Conversion from mpg to Mg is explained in the notes to table 4.

represents a safety valve policy that prevents marginal costs from going above f_N.[28]

Result When Both Firms Must Comply with Both Regulations

What is the effect of the binding EPA regulation with credit trading on the NHTSA outcome? Firm 1 is more than complying under the EPA rules, so it has already paid for reductions up to Mg_E. Firm 1 could now sell credits in the NHTSA market ($Mg_E – Mg_T$ equivalent for NHTSA units), but the opportunity cost of these reductions is now zero. Firm 2 is reducing up to Mg_E under the EPA standard with trading, so it does not meet the NHTSA standard. It could pay the fine for the additional mpg needed to meet the standard, but firms like Firm 1 have already earned EPA credits and should be willing to sell at less than f_N, possibly at a price close to zero.

The result is that because the two regulations have effectively the same target, the sum of the credit prices should equal the marginal cost of reducing fuel use (or equivalent CO_2 emissions). Firms will not pay twice for essentially the same reductions. In the case where the EPA standards are binding and no fine is allowed, an EPA credit market with a price such as P_E per Mg is likely to develop, and the price should closely reflect marginal costs. No NHTSA fines would be paid, and the NHTSA credit price may be close to zero.[29]

A3. Effects of Other Regulations: Zero Emission Vehicle Regulations in California and Participating States

Other regulations may also have an effect on the CAFE credit markets. One such regulation is the Zero Emission Vehicle (ZEV) mandate in California and participating states.[30] The ZEV mandate requires that a certain percentage of vehicles sold in participating states be “zero emitting,” which currently includes only pure electric or fuel cell vehicles. The required percentage for the large-volume manufacturers is as high as 15 percent by 2025, which has important implications for the fleet of vehicles that these manufacturers will sell, because the participating states make up about 25 percent of the US market.

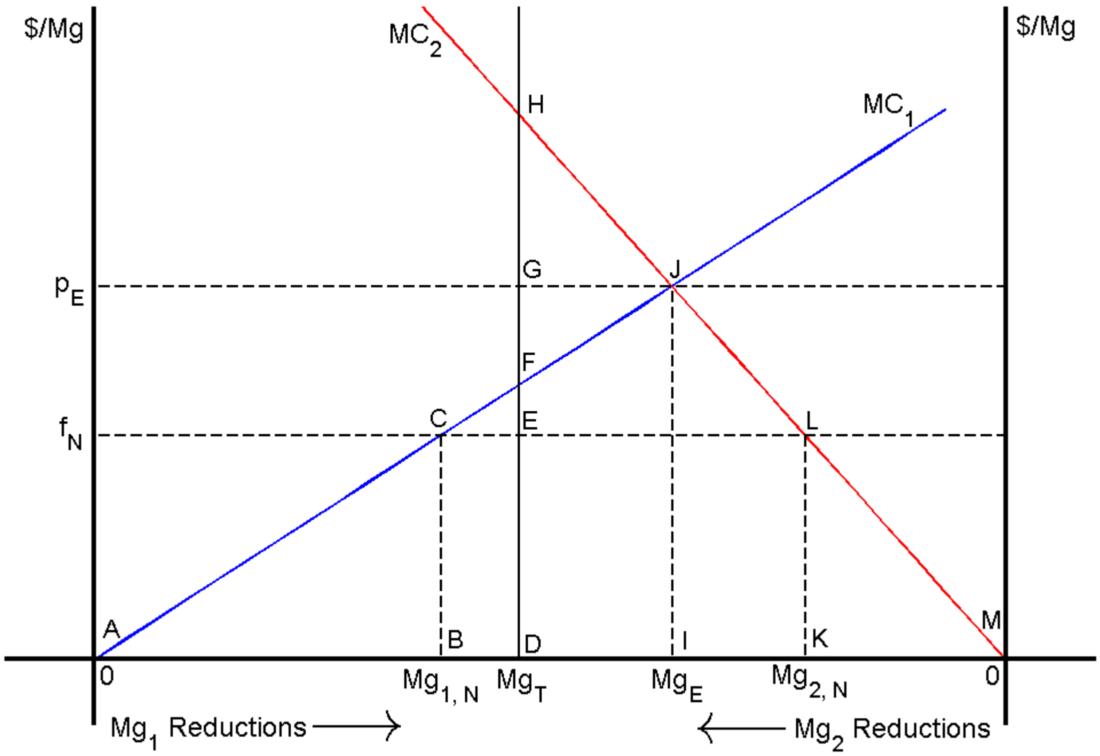
If firms that sell vehicles in California have to sell ZEV vehicles, then the costs of meeting the CAFE standards with the remaining vehicles in their fleets will be lower than they would be in the absence of the ZEV mandate. However, the companies’ costs of meeting the CAFE standards *overall* are higher because they are required to produce and sell more ZEV vehicles than they would choose to, in order to meet the standards at the lowest cost.

[28] It is possible that the fine is higher than Firm 1’s marginal costs at the target standard but still below the cost of complying for Firm 2. A limited NHTSA market for credits may develop if auto companies are willing to trade with each other at costs slightly lower than the fine. Under these circumstances Firm 2 would still pay some fines but would also purchase some credits from Firm 1.

[29] In the presence of other differences in credit allowances and limits to trading, the outcomes in the credit markets will be more complex than described here. For example, companies can earn credits in different ways (see table 1).

[30] For details on the ZEV mandate, see http://www.arb.ca.gov/msprog/zevprog/zevprog.htm.

FIGURE A1. MANUFACTURERS FACING OVERLAPPING REGULATIONS FOR IMPROVING FUEL ECONOMY AND REDUCING CO_2 EMISSIONS



Note: Figure is shown in terms of marginal cost of reducing emissions of CO_2 (in Mg), but it could be shown instead in terms of cost of fuel economy improvements.