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Interpreting Tradable Credit Prices in Overlapping Vehicle Regulations

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Abstract

Prices of tradable credits in environmental regulations reveal information about abatement costs. This information guides regulatory assessments and future changes to the regulations. When regulations overlap, however, simple interpretations of credit prices no longer hold. We derive formulas for interpreting the value of credit prices for three overlapping regulations for passenger vehicles: corporate average fuel economy (CAFE) standards, greenhouse gas (GHG) standards, and zero emissions vehicle (ZEV) programs. Our assessment reveals that the marginal costs of reducing GHGs from conventional gasoline vehicles are virtually equal to the sum of CAFE and GHG credit prices, since each policy regulates emissions in nearly the same way. We estimate that these costs range between $40 and $120 per ton of carbon. In contrast, marginal costs of selling one additional ZEV are $9,000 to $20,000, which are higher than the ZEV credit price. This is due to the compliance value of selling a ZEV achieved under the CAFE and GHG programs.

Keywords: credit prices, overlapping environmental regulations, transportation policy
JEL codes: L51, L62, Q41, Q58

Contents

1. Introduction

The transportation sector is undergoing a rapid transformation in the United States. New cars and light trucks are achieving record levels of fuel economy, and the share of electric vehicles continues to expand. These transitions are partly due to federal and state policies, including federal corporate average fuel economy (CAFE) and greenhouse gas (GHG) standards and state-level zero emissions vehicle (ZEV) mandates imposed on each manufacturer. The federal standards set by the Obama administration require a year-over-year increase in manufacturer fleetwide fuel economy and an equivalent reduction in GHG emissions of new vehicles sold in the United States. Meanwhile, 12 states led by California have adopted their own ZEV mandates for manufacturers, to expand the market share of electric vehicles.

These three regulations represent the most ambitious and comprehensive policies in the transportation sector for addressing climate change. Given their scope, the policies have often been criticized for being an expensive method of achieving climate goals. One way that policymakers have addressed this concern is to provide additional compliance flexibility for vehicle manufacturers in the form of credit trading. All three policies include a trading program to allow flexibility for manufacturers to meet the separate requirements.

The basic structure of the credit-trading programs is similar to that of a cap-and-trade program. Manufacturers are able to earn credits by overcomplying with each of the separate requirements. These credits can be sold to other manufacturers that are undercompliant. This trading reduces compliance costs, as it allows more abatement to occur by manufacturers that have the lowest marginal abatement costs.

The programs have three separate credit systems: one for the CAFE program, one for the GHG program, and one for the ZEV mandate. Leard and McConnell (2017) provide a detailed description of the CAFE and GHG credit markets, and McConnell et al. (2019) describe the ZEV credit market.

Credit prices reveal information about abatement costs. In a stylized setting with a single regulation and no distortions, credit prices reveal the marginal cost of abatement. This information can be used to estimate costs of the regulation, which can guide regulatory impact analysis assessments and future changes to the regulation. But in the current setting with three overlapping regulations, this simple result may not hold. Prior literature on overlapping regulations has focused on emissions leakage (Goulder and Stavins 2011; Goulder et al. 2012; Roth 2015) and alternative policy cost comparisons (Anderson et al. 2016). In this paper, we present a simple analytical model to explore the effects of having multiple overlapping regulations on the interpretation of credit prices.

Our model reveals three key findings. First, using simple closed-form formulas for computing marginal abatement costs, we find that multiple credit prices must be known to infer information about marginal costs of a single regulation. Second, while the marginal costs of reducing GHG emissions from gasoline vehicles can be inferred from CAFE and GHG credit prices, computing the marginal costs of mandating ZEVs requires credit prices from all three crediting programs. Third, we calibrate our formulas to estimate marginal costs of abatement. We find that the marginal cost of reducing GHGs is nearly equal to the sum of CAFE and GHG credit prices, as each policy regulates emissions in the same way. We also find that the marginal cost of selling one additional ZEV is about twice as large as the ZEV credit price, due to the compliance value of selling a ZEV gained under the CAFE and GHG programs.

2. Model

In this section, we present a model for determining relationships between marginal costs of the three regulations and credit prices. We make a series of assumptions to keep the model analytically tractable.

Consider a setting where vehicle manufacturers make decisions to comply with CAFE standards, GHG standards, and a ZEV mandate. For simplicity, we model a single new vehicle market. Manufacturers sell a representative gasoline vehicle that is defined by its lifetime emissions. Manufacturers also sell a representative electric vehicle that has measured tailpipe emissions equal to zero.

To mimic current federal regulations, the CAFE and GHG regulations are harmonized except that the GHG program allows manufacturers to overcredit electric vehicles at a ratio of two to one. That is, the sale of an electric vehicle counts twice when calculating fleet emissions. The current CAFE program does not allow such overcrediting.

Manufacturers make multiple compliance decisions. They choose emissions per mile of their composite gasoline vehicle, the fraction of their fleet that qualifies as a ZEV, and credit purchases and sales to minimize compliance costs. Manufacturers take their own and other manufacturers' vehicle sales as given when minimizing compliance costs. Vehicle attributes besides emissions per mile and the fraction of the fleet that qualifies as a ZEV are exogenous to individual manufacturer decisions.

Credit prices are exogenous to individual manufacturer decisions and are endogenously determined by equating the supply and demand for each credit type. The standards and the mandate have perfectly competitive credit markets.

In this setting, three separate credit markets exist: one for GHG credits, one for fuel economy credits, and one for ZEV credits. The manufacturer chooses average lifetime emissions for gasoline vehicles that do not count as ZEVs, denoted by e_g, and the percentage of vehicles in its fleet that do count as ZEVs, denoted by $\phi > 0$. Lifetime emissions of ZEVs are denoted by e_z and are assumed to be equal to zero: $e_z = 0$. To use the same unit of measurement for vehicle attributes, we model the CAFE standard in units of GHG emissions, which are inversely proportional to miles per gallon. For the CAFE standard, average lifetime emissions for all vehicles in the manufacturer's fleet are

$$e_{CAFE} = \phi e_z + (1 - \phi) e_g = (1 - \phi) e_g. \quad (1)$$

Computing average emissions for the EPA program is more complex because of its treatment of electric vehicles. The EPA program currently overcredits electric vehicles by a ratio of two to one when calculating a manufacturer's average emissions. To account for overcrediting, we use a parameter $\gamma \geq 1$ to represent the ratio of overcrediting allowed. The EPA estimate of average measured tailpipe emissions for all vehicles in the manufacturer's fleet is then

$$e_{EPA} = \frac{(1-\phi)}{1-\phi+\gamma\phi} e_g. \quad (2)$$

When $\gamma > 1$, $e_{EPA} < e_{CAFE}$, as the manufacturer's fleet according to EPA appears cleaner than its fleet according to CAFE. The ZEV mandate requires that ZEVs make up a certain fraction of the manufacturer's fleet, ϕ. We can express this mandate in terms of total ZEVs required to be sold, which is denoted by ZEV. The total number of ZEVs sold by the manufacturer is $n\phi$.

Manufacturers minimize the costs of reducing emissions to meet the three separate regulations. Abatement costs are split into two components: $C_g(\overline{e}_g - e_g)$ represents the cost of reducing emissions of gasoline vehicles; C_z represents the nonregulatory costs of selling a ZEV—that is, the lost profits from selling a ZEV instead of a conventional vehicle in a setting without regulation.[1] In addition to trading x EPA and y CAFE credits, the manufacturer can trade z ZEV credits. The conversion rate between selling a single electric vehicle and earning ZEV credits is θ, so that each vehicle sold earns the manufacturer θ credits. ZEV credit prices are denoted by p_z and are denominated in dollars. The manufacturer solves

$$\min_{e_g,\phi,x,y,z} \{\phi n C_z + (1-\phi) n C_g(\overline{e}_g - e_g) + p_x x + p_y y + p_z z\} \quad subject\ to \quad (3)$$

$$e_{EPA} - \frac{x}{n} \leq GHG_{EPA}, \quad (4)$$

$$e_{CAFE} - \frac{y}{n} \leq GHG_{CAFE}, \quad (5)$$

$$n\phi + \frac{z}{\theta} \geq ZEV, \quad (6)$$

and emissions equations (1) and (2). Assuming that the constraints are binding, substituting the constraints into (3) reduces the manufacturer problem to

[1] Selling ZEVs can be thought of as abatement, since companies are reducing emissions by substituting high-emitting gasoline vehicles for ZEVs.

$$\min_{e_g,\phi}\{\phi nC_z + (1-\phi)nC_g(\bar{e}_g - e_g) + np_x\left[\frac{(1-\phi)}{1-\phi+\gamma\phi}e_g - GHG_{EPA}\right] +$$

$$np_y[(1-\phi)e_g - GHG_{CAFE}] + \theta p_z(ZEV - n\phi)\}. \quad (7)$$

The first-order condition for e_g is

$$-(1-\phi)nC_g{}' + np_x\frac{(1-\phi)}{1-\phi+\gamma\phi} + np_y(1-\phi) = 0. \quad (8)$$

Simplifying and rearranging this condition yields

$$C_g{}' = \frac{p_x}{1-\phi+\gamma\phi} + p_y. \quad (9)$$

This condition shows that the marginal cost of reducing emissions per conventional vehicle equals the sum of the credit prices adjusted for overcrediting of electric vehicles in the EPA program. Without overcrediting, the condition becomes $C_g{}' = p_x + p_y$. The intiuition is that the marginal cost of reducing GHG emissions is the sum of the two credit prices because the two programs essentially do the same thing: improving fuel economy reduces gasoline use and GHG emissions. Overcrediting of electric vehicles by EPA creates a wedge between marginal costs of the CAFE and GHG programs and the sum of the credit prices. Marginal costs are lower with the overcrediting than they would be without because other vehicles will have to reduce less when electric vehicles are counted as more than one. The adjustment is proportional to the market share of electric vehicles (ϕ) and the crediting ratio (γ).

The first-order condition for ϕ, the share of electric vehicles, is

$$nC_z - nC_g(\bar{e}_g - e_g) - np_x\frac{\gamma}{(1-\phi+\gamma\phi)^2}e_g - np_ye_g - n\theta p_z = 0. \quad (10)$$

Simplifying and rearranging this condition yields

$$C_z = \theta p_z + C_g(\bar{e}_g - e_g) + \left[p_x\frac{\gamma}{(1-\phi+\gamma\phi)^2} + p_y\right]e_g. \quad (11)$$

Equation (11) makes it clear that the marginal costs of a ZEV depend on compliance with all three regulations: the ZEV, the GHG, and CAFE regulations. To describe the interaction, we rewrite equation (11) in terms of the ZEV price:

$$\theta p_z = C_z - C_g(\bar{e}_g - e_g) - \left[p_x\frac{\gamma}{(1-\phi+\gamma\phi)^2} + p_y\right]e_g. \quad (12)$$

The left-hand side in equation (12) is the ZEV credit price p_x times the number of credits per ZEV, θ. This is the credit value of a ZEV sale to the manufacturer. In equilibrium, this is equal to a manufacturer's willingness to pay for ZEV credits per ZEV. The first component on the right side of equation (12) is the added costs of producing and selling a ZEV relative to an equivalent gasoline vehicle.[2] The second component, $C_g(\overline{e}_g - e_g)$, is the average cost of reducing emissions from conventional vehicles. This component can be interpreted as an output effect. Holding constant total sales, as the share of electric vehicles increases, fewer gasoline vehicles are sold. When this happens, the manufacturer faces lower total CAFE and EPA compliance costs per ZEV sold. Therefore, the manufacturer is willing to pay less for ZEV credits for each ZEV vehicle sold by an amount equal to the avoided cost of reducing emissions from a conventional gasoline vehicle.

The third component is the per gasoline vehicle value of the GHG and CAFE credit prices. Selling one more ZEV implies that a manufacturer incurs a lower marginal abatement cost by one fewer gasoline vehicle. This component can be interpreted as a marginal abatement effect. The value to the manufacturer of lower marginal abatement costs of the GHG and CAFE standards is equal to the sum of the GHG and CAFE credit prices with an adjustment factor for the EPA credit price. The EPA credit value is adjusted based on the overcrediting ratio γ. The greater the ratio, the greater the value under federal rules of another ZEV.

These last two terms in equation (11) both create a wedge between the marginal costs of producing another ZEV and the ZEV credit price per vehicle. The ZEV credit price is less than the marginal costs of another ZEV relative to a gasoline vehicle because the EPA and CAFE regulations are overlapping with the ZEV requirement. The larger the overcrediting provision for ZEVs that is part of EPA's GHG regulation, the larger this wedge becomes.

[2] Without GHG and CAFE regulations, this is the only component that would remain in the equation, and (12) simplifies to $\theta p_z = C_z$. Thus, the cost of selling one additional ZEV would equal the ZEV credit price per vehicle.

3. Estimation of Marginal Abatement Costs

We can use the analysis above to shed light on manufacturers' marginal abatement costs. We estimate equation (9) for the marginal cost of reducing GHG emissions from gasoline vehicles and equation (11) for the marginal cost of selling a ZEV. The initial estimates below assume an average manufacturer optimizing across a car and truck fleet and are for the model year 2017 vehicles. Electric vehicles are assumed to be similar to a 2017 Tesla Model S in the first case and to a 2017 Nissan Leaf in the second.

We first estimate equation (9). Parameter values are given in Table 1, and the equation is shown in the first row of Table 2. We follow the approach of Leard and McConnell (2017) to estimate the credit price of a GHG credit with binding EPA regulations, p_x. We use revenue from non-ZEV credit sales by Tesla and divide by the number of GHG credits sold by Tesla. For the 2017 model year, we estimate the credit price as $40.31 in 2017$. We assume that CAFE credits are worth the same as EPA credits when denominated in tons of CO_2, since they represent the same compliance value.[3] We use the current allowance ratio of 2 for EPA overcrediting of electric vehicles, γ. We use the average percentage of ZEV sales as a percentage of a manufacturer's fleet of 1 percent, based on 2017 national sales data. Plugging these parameter values into equation (9) yields an estimate of the marginal cost of reducing GHGs from gasoline vehicles of $81 per ton of CO_2.

To get an estimate of the marginal cost of producing and selling a ZEV relative to a gasoline vehicle, we need estimates of the parameters in equation (11). We show the components of equation (11) in Table 2, and again the parameter values are in Table 1. The estimate of the cost of GHG and CAFE regulations on a gasoline engine, $C_g(\overline{e}_g - e_g)$, is from EPA estimates of these costs from the 2012–16 and 2017–25 model year rulemakings. The estimated ZEV credit price is from McConnell et al. (2019), and the number of ZEV credits per vehicle is the number a Tesla Model S was allowed in 2017. Finally, we need an estimate of e_g, lifetime emissions of GHGs from a gasoline vehicle. We use estimates for 2017 from the EPA rulemaking and convert grams per mile to tons per vehicle.

[3] In the sensitivity analysis, we explore the robustness of our results by varying the price of CAFE credits.

The last two rows of Table 2 show the results for the marginal costs of producing and selling a ZEV. The credit price for a Tesla vehicle, $8,872, is well below the additional cost of a ZEV, which we estimate to be $16,281. This is because the savings from reduced costs of complying with the federal program on GHGs and CAFE standards must be accounted for. We find the wedge between ZEV costs and the ZEV credit price to be relatively large, in part because of the overcrediting of ZEV by EPA's GHG rules. If the EPA overcrediting ratio was 1 instead of 2, the marginal abatement effect in Table 2 would fall. This effect is large because it represents a significant reduction in the compliance burden of the EPA program, where the reduction is directly proportional to the EPA credit price.

4. Sensitivity Analysis

To see how our assumptions affect our estimated abatement costs, we vary values for several key parameters and recompute equations (9) and (11). We vary the assumed CAFE credit price, the ZEV credit price, the ZEV percentage, the EPA ZEV crediting ratio, the fuel economy technology cost, and gasoline vehicle lifetime GHG emissions. The assumed CAFE credit price has a significant impact on the cost of reducing GHG emissions from gasoline vehicles.

We find that a plausible range for the CAFE credit price implies a marginal abatement cost of $40 to $120 per ton. Besides the ZEV percentage, which has little effect on abatement costs, varying the parameters has a moderate impact on the cost of selling a ZEV. We find that this cost ranges between $9,000 and $15,000 for the Leaf, depending on the set of assumptions used.

5. Discussion

There are several caveats to this analysis. Credit prices are likely also a function of the number of banked credits that manufacturers hold. In 2017, many automakers held large stocks of both ZEV and GHG credits, some of which would expire in a relatively short time. We do not account for the past behavior or past regulations. Moreover, the analysis does not account for other dynamic aspects of the credit markets. The analysis assumes manufacturers take account of costs and regulations only in the current year, and not in future years. Cost in any given year will depend on the cost and emissions reductions over time, in response to technology constraints and expected changes in regulations. Therefore, our model should be interpreted as representing the regulation over a window of compliance years, such as over a five-year period while the credits remain fungible.

Furthermore, an important extension to this analysis would be to account for the effect of uncertainty on manufacturer decisions. The ZEV mandate has undergone a series of changes during its history, and manufacturers would be likely to make credit purchase decisions to hedge against this uncertainty.

6. Conclusions

As with many other sectors, the transportation sector currently has a patchwork of regulations that aim to reduce greenhouse gas emissions. Some of these regulations allow credit trading as a way to reduce compliance costs. Similar to a cap-and-trade program, these credit-trading provisions reveal economic information about marginal abatement costs, which is valuable for assessing the costs of the programs. However, since the programs overlap, the standard interpretation that credit-trading prices *equal* marginal costs of abatement no longer holds. With a simple analytical model of compliance behavior, we have formalized this for three distinct passenger vehicle regulations: GHG emissions standards, fuel economy standards, and ZEV programs. We have provided intuitive formulas for interpreting the value of observed credit values and shown that credit prices of an individual program can be much different from marginal compliance costs. In our example above, using parameter values based on regulatory stringency in the 2017 model year, the cost of selling an additional ZEV can be over twice as large as the credit price per ZEV.

Our analytical framework can be used to interpret other overlapping regulations. For example, California currently has both a cap-and-trade program for GHG emissions and a low-carbon fuel standard, both of which allow permit trading. Our framework suggests that the marginal costs of reducing GHG emissions may be significantly higher than observed permit prices in either program. We leave estimating the magnitude of this difference for future research.

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Tables

Table 1. Assumptions for Calculating Marginal Compliance Costs, 2017 Model Year (MY)

Description	Term	Assumed Value	Data Sources
EPA credit price	p_x	$40.31	Leard and McConnell (2017); Tesla Quaterly Reports for 2017, 2018; EPA (2018)
CAFE credit price	p_y	$40.31	EPA credit price
ZEV credit price	p_z	$2,218	McConnell et al. (2019)
ZEV credits per EV (Model S)	θ	4	Credits for a 2017 Tesla Model S[a]
ZEV credits per EV (Leaf)	θ	1.8	Credits for a 2017 Nissan Leaf[a]
ZEV percentage	ϕ	0.01	EPA (2018)
EPA ZEV crediting ratio	γ	2	EPA (2011)
Fuel economy technology cost	$C_g(\overline{e}_g - e_g)$	$1,397	EPA (2010); EPA (2011), Tables 4-6, and 4-7; EPA (2012), Table 5.1-9.
Gasoline vehicle lifetime GHG emissions (tons)	e_g	50.37	Grams of CO_2 per mile are from EPA (2010) and EPA (2012), 4-129, Table 4.3-12.[b]

Note: Monetary values are denominated in 2017$.

[a] **https://www.ucsusa.org/resources/what-zev**.

[b] Lifetime miles are assumed to be 195,264.

Table 2. Calculation of Marginal Abatement Costs

Equation	Description	Term	Value
(9)	Marginal cost of reducing GHGs from gasoline vehicles ($/ton)	$\frac{p_x}{1-\phi+\gamma\phi}+p_y$	$81.02
	ZEV credit price per ZEV (Model S)	θp_z	$8,872
	ZEV credit price per ZEV (Leaf)	θp_z	$3,992
	Output effect	$C_g(\overline{e}_g-e_g)$	$1,397
	Marginal abatement effect	$\left[p_x\frac{\gamma}{(1-\phi+\gamma\phi)^2}+p_y\right]e_g$	$6,012
(11)	Sum of ZEV costs (Model S)	$\theta p_z+C_g(\overline{e}_g-e_g)+\left[p_x\frac{\gamma}{(1-\phi+\gamma\phi)^2}+p_y\right]e_g$	$16,281
	Sum of ZEV costs (Leaf)	Same as above but θp_Z for the Leaf is used	$11,402

Note: Monetary values are denominated in 2017$.

Table 3. Sensitivity Analysis

Parameter	Level	Value	Marginal cost of reducing GHGs from gasoline vehicles ($/ton)	Marginal cost of selling a ZEV (Model S assumptions)	Marginal cost of selling a ZEV (Leaf assumptions)
CAFE credit price ($/ton)	Low	0	39.91	14,250	9,371
	Benchmark	40.31	80.22	16,281	11,402
	High	80.62	120.53	18,312	13,432
ZEV credit price ($)	Low	1,664	80.22	14,063	10,403
	Benchmark	2,218	80.22	16,281	11,402
	High	3,327	80.22	20,717	13,398
ZEV percentage (ϕ)	Low	0.005	80.42	16,321	11,441
	Benchmark	0.01	80.22	16,281	11,402
	High	0.02	79.83	16,204	11,324

EPA ZEV crediting ratio (γ)	Low	1	80.62	14,330	9,451
	Benchmark	2	80.22	16,281	11,402
	High	4	79.45	19,956	15,077
Fuel economy technology cost ($/vehicle)	Low	1,048	80.22	15,932	11,052
	Benchmark	1,397	80.22	16,281	11,402
	High	2,096	80.22	16,980	12,100
Gasoline vehicle lifetime GHG emissions (tons)	Low	37.78	80.22	14,778	9,899
	Benchmark	50.38	80.22	16,281	11,402
	High	75.57	80.22	19,287	14,408

Note: Monetary values are denominated in 2017$.