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To Rebate or Not to Rebate: Fuel Economy Standards vs. Feebates*

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Abstract

We compare the welfare effects in equilibrium of two environmental regulations that aim at increasing the new cars fleet's average fuel efficiency: the fuel economy standards and the feebate policies. Maintaining the same environmental benefit and tax revenue, we simulate the implementation of each policy in France and the United States. Standard-type policies have larger negative welfare effects, up to 1.7 times those from the feebate. Effects on manufacturers are heterogeneous: some are better off under the standard regulation. The addition of a market to trade levels of fuel efficiency dominates the simple standard regulation and the feebate. We also consider the attribute-based standard, technological improvements, and the equivalence with fuel taxes as extensions.

JEL codes: C51, Q51, L50

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1 Introduction

Environmental regulations have been introduced in most developed countries in the past ten years to reduce carbon dioxide emissions related to new cars. There are two major types of environmental policies that target the market for new vehicles: the fuel efficiency standards that constrain manufacturers, and consumer taxes or subsidies. In the United States, the Corporate Average Fuel Economy (CAFE) standards have been in place since 1978 and have been strengthened twice during the past 39 years. They impose a minimum threshold of fuel efficiency for manufacturers to be met with their sales-weighted average of fuel efficiency. A fine is paid if there is no compliance.

More recently, a CO_2 emissions standard regulation has been introduced in Europe. The *mandatory emissions target reductions* regulation became fully binding for the first time in 2015 after an experimental stage that started in 2012. However, fuel efficiency or CO_2 emissions-based purchasing taxes have been common in European countries such as Germany and the United Kingdom since before. Other countries have introduced subsidies for fuel efficient and alternative fuel or hybrid vehicles. This is the case of Sweden with its "Green Car Rebates program" and of the "Running on Green Power" rebate program for electric vehicles in Canada. The combination of fees and rebates schemes, or feebates, has been in place in large jurisdictions, such as California in the U.S. and Wallonia in Belgium, and in entire countries, such as in France through the "bonus/malus" policy since 2008.

This paper analyses and compares the fuel efficiency standard and feebate instruments. Both regulations share the same objective −to improve the fuel efficiency of new vehicles− but differ in their implementation. We quantitatively investigate their effects using product-level data from the U.S. and the French automobile markets together with a structural model of market equilibrium to determine whether one policy dominates the other for different levels of the regulation stringency. The question of policy efficiency is non-trivial as it crucially depends on the weight allocated to the policy outcome relative to the welfare effects. Instead, we develop a framework that allows us to carry a fair comparison by simulating the effects of the two policies when they are equivalent in terms of (i) the fleet-wide fuel efficiency outcome and (ii) the total amount of tax revenue raised. We compare welfare effects of the two policies both at the aggregate level and across manufacturers. Since these two countries differ in several dimensions, comparing the same policies in each of them allows us to draw conclusions that extend beyond the characteristics of one particular market.

We focus on the short-term incentives induced by the regulations, i.e. the manufacturers' reactions through the modifications of the prices, and we rule out the possibility to design new models or improve the fuel efficiency of the existing car models. Both policies give the same long-term incentives: a manufacturer will improve the fuel efficiency of its vehicles to avoid the constraint under the fuel efficiency standard, or to take advantage of subsidies given to consumers when there are feebates.

Under the CAFE standard, manufacturers have an incentive to lower the price of cars with high fuel efficiency and to increase the price of those with low fuel efficiency in order to comply with the regulation or reduce the penalties. Since there are strategic interactions between manufacturers, the changes in prices for a given manufacturer depend on how affected its competitors are. Feebate-type policies modify the final prices faced by the consumers. The manufacturers, anticipating the amount of rebates or taxes paid by consumers in addition to the posted prices, have incentives to decrease the posted prices of fuel inefficient vehicles and increase the prices of fuel efficient vehicles.

Gasoline taxes would provide a first best solution to this externality problem, but given the political aspects associated with them, we abstract from their discussion for the main results and focus solely on those two other policies that are a second best solution notwithstanding. In the extensions to the model we compare the two policies to an equivalent fuel tax increase. There have been a number of previous studies on the short-term effects of increasing the U.S. CAFE standards (Goldberg [1998], West [2004], Kleit [2004], Austin and Dinan [2005], Gramlich [2009], and Jacobsen [2013]) and on the European feebate programs (Adamou et al. [2014], D'Haultfœuille et al. [2014], Huse and Lucinda [2014], and D'Haultfœuille et al. [2016]) but very few on the empirical cross-policy comparison. One of the closest studies to ours is Gillingham [2013] who uses the National Energy Modelling System (NEMS) to simulate CAFE policies and contrast them with a feebate policy. We find similar results in the ranking of the two policies. Another study due to Roth [2015], who analyses the two policies and their complementarity with R&D incentives and vehicle tax credits using a general equilibrium approach. Our method differs from those studies in that they neglect strategic interactions between manufacturers.

The attribute-based version of the CAFE standards has sprung a novel strand of the literature, as in the work by Ito and Sallee [2015] who analyse the theoretical aspects of the incentives to modify products' characteristics and find evidence of such changes in the Japanese car market. Another example is Reynaert [2015] who investigates manufacturers' reactions to the European attribute-based standard, taking into account trends of past technological adoption. Whitefoot et al. [2015] and Huse and Lucinda [2015] endogenise technological decisions coupled with pricing strategies. The first make use of engineering design functions to predict car characteristics whereas the second uses estimates based on observable attributes. In either case, their problem is equivalent to finding equilibrium solutions over two or more vectors where one of them corresponds to the equilibrium prices. We also consider scenarios with technological improvements on the fuel efficiency. Unlike the two aforementioned studies, we circumvent the potential problems of multiplicity of equilibria by exogenously allowing the imports of existing car models in Europe into the American market and by introducing hybrid versions of existing car models.

We start with a series of theoretical results that compare the two policies under simple market structures. We show that the policies are welfare equivalent under symmetry of manufacturers and full compliance. When we depart from the symmetry assumption, we are only able to compare the magnitude of price distortions. We also assess the changes caused by the attribute-based standards and a trading system for fuel efficiency similar to those in the 2011 CAFE regulations in the U.S. and the 2015 European standard.

We use data that consist of all sales of new cars in France and the U.S. by car model and their main characteristics. We are able, using a nested logit demand system, to recover parameters of preferences such as price sensitivities and valuations of car attributes. Using a structural model of supply, and assuming that market outcomes correspond to those of a Bertrand-Nash equilibrium, we recover estimates of marginal costs for all the products in the market. Then we simulate the introduction of the two regulations for different levels of stringency and compare the effects on policy outcomes −consumer surplus, distribution of profits, and welfare.

Our results show that CAFE standard policies are consistently dominated by feebate policies. As we increase the stringency of the policies, welfare losses monotonically increase in both the U.S. and France. However, we find important differences between the two countries. Welfare losses from a standard-type policy in the U.S. are about 1.1 times those of an equivalent feebate-type policy that achieves the same improvement in fleet-wide fuel efficiency and the same amount of tax revenue. In France, this difference is larger: up to 1.7 times depending on policy parameters. We decompose these welfare losses at the individual manufacturer level and find large amounts of heterogeneity in the effects on profits, indicating that for some firms the standard regulation would be preferred over the feebate. Including the welfare gains from the reduction in CO_2 emissions leads to similar conclusions since welfare levels change by amounts less than 1%.

We also study the effects of the new formats of CAFE standards. In the case of trading of credits on top of the regular standard, welfare is larger than in the traditional standard and feebate regulations for both countries. Attribute-based standards relax the constraint with respect to the traditional CAFE standard policy for the U.S. but not in France.

As extensions of the model we consider two forms of technological improvements. First, we allow for imports of French car models into the U.S. that would contribute towards compliance. This reduces the losses in welfare relative to our benchmark scenario. Second, we allow for the introduction of hybrid versions of existing car models and we find that feebate policies become welfare-improving in both markets while the standard is welfare improving in the U.S. only when including benefits from the reduction in CO_2 emissions. As a final extension, we compute the equivalent fuel tax in each market that would yield the same fuel efficiency as in our benchmark case. We obtain an equivalent fuel tax of 32% for the U.S. and 15% for France. These numbers put in perspective our welfare results and indicate a non-negligible effect on taxes if this was the preferred policy to be used.

The rest of this paper is organised as follows. In Section 2 we describe the two environmental policies. In Section 3 we introduce the model for each policy and some theoretical insights into the comparison of the policies. Section 4 describes the data and estimation results. The simulation outcomes and policy comparisons are presented in Section 5. We conclude with Section 6.

2 Environmental Policies

The CAFE standard regulations implemented in the U.S. and Canada consist of, in their most general form, a threshold of fuel economy that each manufacturer's fleet average must meet. This regulation has a long history, starting as a response to the Arab oil embargo in 1973-1974. A manufacturer's CAFE is the weighted harmonic mean of miles per gallon of all the cars in a manufacturer's fleet for a given year. The weights are derived from the number of vehicles sold during that year. Compliance occurs when the manufacturer's CAFE is above the standard for that year. When a manufacturer's CAFE is below the standard, it incurs a penalty of $55 per mile per gallon under the target value times the total volume of vehicles sold in a given year.

Since 1983, manufacturers have paid more than $500 million in penalties. The CAFE standard is a policy that primarily affects the supply side of the automobile market. It is not clear how much of the constraint imposed by the regulation is passed-through to the prices paid by consumers. Moreover, this policy only affects the extensive margin since, once the vehicle has been purchased, the policy has no direct effect on the intensive margin, as opposed to a gasoline tax which has a direct effect on the intensive margin of both old and new vehicles.

Starting with car models 2012, the U.S. changed the way CAFE standards are implemented. They are now a function of the car's footprint size –the area obtained by multiplying the length of the wheelbase and the car's width– establishing stricter thresholds for smaller cars. Since these modifications depend on a physical characteristic of the vehicle and not just the car's maker, this version of the CAFE is referred to as "attribute-based". These changes also include rulemakings to trade levels of fuel efficiency among manufacturers.[1]

In Europe, a standard-type policy has been implemented in recent years but it defines the threshold in terms of CO_2 emissions instead of fuel efficiency. This emissions reduction target program was first implemented in a non-binding form in 2012. For 2015, the law requires that the new cars have less than 130 grams of CO_2 emissions per kilometer. The corresponding target for 2020 is 95 (European Commission [2015]).

In France, the "bonus/malus" policy was introduced in 2008 and attempts to improve fuel efficiency by targeting consumers directly. It is a scheme of fees and rebates (feebate) based on CO_2 emissions of new cars. Initially, this system was designed to be revenue-neutral: taxes were meant to exactly offset the total amount of rebates. Its purpose was to lower the average emissions produced by cars to reach 130 grams of CO_2 per kilometer by 2020. Similarly, California proposed a feebate program in 2008 which eventually was merged into the new structure of the CAFE standards that went into effect at the federal level in 2011.[2]

The 2008 French policy consisted of a financial rebate, from 200 to 1,000 euros, given to consumers purchasing low CO_2 emissions level vehicles (less than 130g/km). Consumers buying polluting cars (more than 160g/km) were taxed, from 200 to 2,600 euros. The exact amount of the rebate or the fee depended on the class of emissions of the vehicle. This feebate was received or paid once, at the time of the sale of the vehicle. It applied to all new cars, including those purchased abroad or manufactured abroad. Thus, unlike the standard regulation, the feebate primarily affects the demand side. However, its effects on the intensive and the extensive margins are similar to those of the CAFE standard policy.

3 The Model

To analyse the effects of these environmental policies, we first estimate the primitives of the U.S. and the French car markets separately. We rely on a structural model of demand and supply for new cars. For the demand system we use a nested logit specification. The demand parameters for new cars are identified from the observed market shares and car characteristics. The supply parameters are recovered assuming manufacturers compete in prices, each selling a set of differentiated products.

[1] NHTSA [2014].

[2] The California's Clean Car Discount program was proposed to go into effect on car models 2011 based on a simple tax and rebate rule.

3.1 Demand Model

Each consumer chooses either to purchase one of J products or not to buy any, which is the outside option denoted by 0. The set of products is segmented in $G + 1$ groups. First, a consumer chooses a group g, and then the consumer chooses a specific car model within this group. Consumers do not have preferences for car models themselves but for the characteristics of the cars, such as horsepower, size, fuel efficiency, or engine type. Those preferences are represented by a linear function of characteristics of car model j following the nested logit model of Berry [1994]:

$$\begin{aligned} U_{ij} &= \delta_j + \zeta_{ig} + (1-\sigma)\epsilon_{ij} \\ \delta_j &= X_j\beta - \alpha p_j + \xi_j \end{aligned}$$

where X_j corresponds to observed characteristics of products, p_j is the price, and ξ_j represents the valuation of unobserved characteristics. The term $\zeta_{ig} + (1-\sigma)\epsilon_{ij}$ represents the idiosyncratic preference shock where ϵ_{ij} is extreme-value distributed, and ζ_{ig} is the group specific random shock that allows for correlation of preferences over cars within the groups. By construction $0 \leq \sigma \leq 1$. If σ is close to 1, all the car models within each group share the same idiosyncratic term and the choice of a product within the segment is deterministic. If σ is close to 0, the segmentation is irrelevant. Berry [1994] discusses how $\zeta_{ig} + (1-\sigma)\epsilon_{ij}$ is also extreme-value distributed. Because of this distributional assumption and since consumers maximize their utility, the log of market share of good j is:

$$\log s_j = \delta_j/(1-\sigma) - \sigma \log D_g + \log s_0$$

with $D_g = \sum_{j \in \mathcal{J}_g} \exp(\delta_j/(1-\sigma))$ where $\mathcal{J}_g$ is the set of car models in group g and s_0 is the share of the outside good. Normalising the mean utility of the outside good to $\delta_0 = 0$ and $D_0 = 1$, we obtain

$$\log s_j - \log s_0 = \delta_j + \sigma \log s_{j|g},$$

where $s_{j|g}$ is the within-segment market share. This is the equation we take to the data. We use an instrumental variable approach to address the endogeneity of prices and the intra-group market share. Following the literature (e.g. Berry et al. [1995]), we construct instruments which are functions of exogenous characteristics of other products.[3] We make the standard assumption that characteristics of cars are fixed while the prices can be adjusted. These instruments are valid since they are correlated to the price through competition. If a product has several close substitutes the manufacturer has less ability to set a high markup.

[3]These instruments are the sums of exogenous characteristics of: (1) other brands, (2) other brands within the segment, and (3) other products of the same brand within the segment.

3.2 Supply Model

We consider an oligopolistic market with a finite number of firms selling differentiated products. These firms are multi-product and set prices based on the demand levels. Profits of firm $m = 1, \ldots, M$ producing the set of goods $\mathcal{J}_m$ are:

$$\Pi_m = \sum_{j \in \mathcal{J}_m} N\,(p_j - c_j)\,s_j(\mathbf{p}).$$

N is the number of potential buyers, $s_j(\mathbf{p})$ is the market share of product j that depends, among other factors, on the vector of prices $\mathbf{p}$ of all the products in the market, and c_j is the marginal cost. Then the optimal price vector satisfies

$$p_k^* = c_k - [\mathbf{\Omega}^{-1}(\mathbf{p}^*)S(\mathbf{p}^*)]_k, \tag{1}$$

where $\mathbf{\Omega}(\mathbf{p})$ is the matrix of derivatives of market shares with respect to prices and $-\left[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})\right]_k$ represents the k^{th} element of the vector of margins defined by $-\left[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})\right]$.[4]

3.3 Introducing Environmental Policies

Fuel Economy Standard

The first policy considered is the introduction of a standard on fuel efficiency levels. We follow the specifics in the implementation in the U.S. A manufacturer's CAFE is defined by the weighted harmonic mean of its cars' fuel efficiency. The rationale behind the use of the harmonic mean is to compute the average fuel efficiency associated with a constant distance traveled by every car. Equivalently, we can define a manufacturer's CAFE using the arithmetic mean of fuel consumption −the inverse of the fuel efficiency− measured in gallons per 100 miles. In this analysis, we use fuel consumption, the practice adopted elsewhere in the literature to simplify the equations (see for example Goldberg [1998] and Roth [2015]). Thus the CAFE standard regulation is defined by a maximum on the average fuel consumption of a manufacturer' fleet,

$$e_m(\mathbf{p}) = \frac{\sum_{j \in \mathcal{J}_m} s_j(\mathbf{p}) e_j}{\sum_{j \in \mathcal{J}_m} s_j(\mathbf{p})}.$$

To comply, manufacturers can only modify the prices, as we assume other characteristics, fuel consumption in particular, to be exogenous and thus fixed. The constraint induced by the standard may lead to large decreases in manufacturers' profits up to the point where it is preferable to pay the penalty and leave e_m above the standard. This payment is always

[4] The matrix $\mathbf{\Omega}(\mathbf{p})$ is constructed as $\mathbf{\Omega}_{kj}(\mathbf{p}) = \frac{\partial s_j(\mathbf{p})}{\partial p_k}$ if $j, k \in \mathcal{J}_m$, and $\mathbf{\Omega}_{kj}(\mathbf{p}) = 0$ if products j and k are not produced by the same firm.

incurred when the manufacturer has no car model with fuel consumption below the standard. Let $\bar{e}$ be the fuel consumption standard imposed by the regulation, the cost of not complying is set to be

$$F_m(\mathbf{p}) = N\phi \sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})(e_m(\mathbf{p}) - \bar{e}) \quad \text{if } e_m(\mathbf{p}) > \bar{e}$$

where ϕ is the unit penalty, and e_m is the manufacturer's fuel consumption average as defined above. The manufacturer has to pay the penalty for every car sold and for each unit of fuel consumption above the standard.

The program of a manufacturer under the standard is:

$$\begin{array}{lll} & \max_{p_{j,j\in\mathcal{J}_m}} \Pi_m(\mathbf{p}) - F_m(\mathbf{p}) & \\ \text{with} & F_m(\mathbf{p}) = 0 & \text{if } e_m(\mathbf{p}) \leq \bar{e}, \\ & F_m(\mathbf{p}) = N\phi \sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})(e_m(\mathbf{p}) - \bar{e}) & \text{if } e_m(\mathbf{p}) > \bar{e}. \end{array} \tag{2}$$

We can distinguish three statuses for manufacturers, and for each one we can express the optimal prices after the introduction of a fuel consumption standard: (i) the ones that change prices in order to comply and do not pay the penalty (the *compliers*), (ii) the ones that prefer to pay the penalty and remain above the standard (the *payers*), and (iii) the ones whose fleet average is already below the standard (the *non-constrained*), these are affected by the regulation only through the strategic interactions with other manufacturers. For each status of manufacturers, we solve the profit maximization problem to obtain the expression for optimal car prices.

(i) The complier case.

The problem of a manufacturer m selling the set of cars $\mathcal{J}_m$ is

$$\begin{array}{ll} & \max_{p_{j,j\in\mathcal{J}_m}} \Pi_m(\mathbf{p}) \\ \text{s.t.} & e_m(\mathbf{p}) \leq \bar{e}, \end{array} \tag{3}$$

where e_m is the manufacturer's average fuel consumption and $\mathbf{p}$ is the vector of all the prices. The complier has no incentive to achieve a fuel consumption level below the standard, therefore the constraint is binding. We consider the following Lagrangian to represent manufacturer's m problem:

$$\mathcal{L}(\{p_{j,j\in\mathcal{J}_m}\}, \lambda_m) = \sum_{j\in\mathcal{J}_m} (p_j - c_j)s_j(\mathbf{p}) - \lambda_m (e_m(\mathbf{p}) - \bar{e}).$$

This Lagrangian takes into account the shadow costs of the policy through the last term of the expression above. The optimality conditions are

$$\begin{cases} \sum_{j\in\mathcal{J}_m}\left(p_j - c_j - \frac{\lambda_m}{\sum_{h\in\mathcal{J}_m} s_h(\mathbf{p})}(e_j - \bar{e})\right)\frac{\partial s_j}{\partial p_k}(\mathbf{p}) + s_k(\mathbf{p}) = 0 \\ \frac{\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})e_j}{\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})} - \bar{e} = 0 \\ \lambda_m > 0. \end{cases}$$

Optimal price of car $k \in \mathcal{J}_m$ with the fuel economy standard regulation satisfies

$$p_k^* = \left(c_k + \tilde{\lambda}_m(e_k - \bar{e})\right) - \left[\mathbf{\Omega}^{-1}(\mathbf{p}^*)S(\mathbf{p}^*)\right]_k$$

where $\tilde{\lambda}_m \equiv \frac{\lambda_m}{\sum_{h\in\mathcal{J}_m} s_h(\mathbf{p})}$. Imposing a fuel economy standard has an effect that can be compared to a change in the marginal costs. If the car model has a higher (lower) fuel consumption than the standard, then the standard has the same effect as an increase (decrease) on the marginal cost of production of this car. The regulation can also be interpreted as an implicit tax (subsidy) on the cars that are above (below) the standard. As a consequence, prices of cars with fuel consumption below the standard decrease, and prices of cars above the standard increase. The magnitude of this effect depends on $\tilde{\lambda}_m$ which reflects how constrained the manufacturer is by the regulation. $\tilde{\lambda}_m$ can be interpreted as an implicit or shadow cost (per unit of fuel consumption) of the regulation; it is manufacturer specific and varies with the policy level of stringency.

The CAFE standard has another effect on prices through the term $[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k$ that is modified by the regulation. However, it is not possible to predict the sign and the magnitude of this indirect effect, which depends on substitution patterns across products and market power of manufacturers. In perfect competition, the term $[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k$ is equal to 0 and the effect of the standard regulation is entirely passed-through to consumers' prices.

(ii) The payer case.

The problem of a manufacturer m that does not comply with the regulation is

$$\max_{p_{j,j\in\mathcal{J}_m}} \Pi_m(\mathbf{p}) - F_m(\mathbf{p}).$$

Solving this program leads to the following first order condition:

$$\sum_{j\in\mathcal{J}_m}(p_j - c_j - \phi(e_j - \bar{e}))\frac{\partial s_j(\mathbf{p})}{\partial p_k} + s_k(\mathbf{p}) = 0.$$

Optimal price of car k under the CAFE standard regulation for a payer satisfies

$$p_k^* = (c_k + \phi(e_k - \bar{e})) - \left[\mathbf{\Omega}^{-1}(\mathbf{p}^*)S(\mathbf{p}^*)\right]_k.$$

The penalty has the same effect of an increase (decrease) in marginal cost for the cars that have fuel consumption above (below) the standard.

(iii) The non-constrained case.

The program of a non-constrained manufacturer is identical to (3), except that there is no constraint on its CAFE. The expressions for the first order conditions are those shown in equation (1): the manufacturer's problem remains unchanged by the introduction of the standard. However, because of strategic interactions, optimal prices are different after the introduction of the standard since the term $[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k$ is modified. A non-constrained manufacturer increases its prices if the manufacturers that produce close substitutes are constrained by the standard regulation.

The vector of equilibrium prices and $\tilde{\lambda}_m$s after the regulation must satisfy simultaneously the first order conditions of all manufacturers. We provide details on how to solve, in practice, this system of equations in Appendix A.

Feebate

The second environmental regulation instrument studied here is the introduction of a purchase tax and subsidy. Specifically, we consider a *feebate* scheme that introduces a tax for all the vehicles with fuel consumption above a certain threshold called *pivot point* and a subsidy for the car models with fuel consumption below the threshold. This policy is parameterised by the pivot point $\tilde{e}$ and the feebate rate $\tau > 0$ of taxation (subsidy) per unit of fuel consumption above (below) the pivot point. We consider a simple feebate scheme that is linear in fuel consumption. In practice, feebates can be non-linear and include discontinuities (as seen in France and California) but we restrict our analysis to a feebate with two parameters as we have only two targets: fuel efficiency outcome and tax revenue. The final price faced by consumers is given by

$$p_j^f = p_j + \tau(e_j - \tilde{e}).$$

Higher values of τ and $\tilde{e}$ make the policy more stringent, as they increase the marginal tax rate and the set of cars taxed, respectively. The manufacturers' objective is modified because all the final prices faced by consumers are different except for those of the vehicles with fuel consumption exactly equal to the pivot point. The profits under the feebate regulation are

$$\Pi_m = \sum_{j \in \mathcal{J}_m} (p_j - c_j) s_j(\mathbf{p^f}),$$

where $\mathbf{p^f}$ is the vector of all the final prices. It is useful to rewrite the manufacturer's problem in terms of final prices as

$$\max_{p^f_{j, j \in \mathcal{J}_m}} \sum_j \left(p_j^f - (c_j + \tau(e_j - \tilde{e}) \right) s_j(\mathbf{p^f}).$$

Therefore $p_k^{f*} = c_k + \tau(e_k - \tilde{e}) - \left[\boldsymbol{\Omega}^{-1}((\mathbf{p}^{f*})S(\mathbf{p}^{f*})\right]_k$. Again, the feebate has the same effect as a cost increase (reduction) when the fuel consumption is above (below) $\tilde{e}$.

Policy equivalence

Our objective is to compare standards and feebates when they are equivalent in terms of fuel efficiency outcome and tax revenue raised. For a given standard policy, we can find an equivalent feebate $(\tilde{e}, \tau)$ such that the policy tax revenue is equal to $R^{\text{CAFE}} = \sum_m F_m$ and the average fuel consumption is equal to the industry's weighted average fuel consumption under the standard, e^{CAFE}. The tax revenue condition is then

$$N \sum_{j=1}^{J} s_j(\mathbf{p})\tau(e_j - \tilde{e}) = R^{\text{CAFE}}$$

together with the policy objective level

$$\frac{\sum_{j=1}^{J} s_j(\mathbf{p})e_j}{\sum_{j=1}^{J} s_j(\mathbf{p})} = e^{\text{CAFE}}.$$

Computational details on how to solve for the new equilibrium under the standard and the feebate and obtain the strict equivalence in terms of fuel consumption outcome and tax revenue are presented in Appendix A.

New Rules for Fuel Economy Standards

The new U.S. CAFE standards rules in place since 2011 allow manufacturers to trade fuel consumption levels through the creation of a market for credits.[5] Manufacturers with a high fleet fuel consumption average can opt to buy some of these credits to use as a substitute for lower fuel consumption vehicles. The equilibrium price of fuel consumption credits is determined by the equality between demand and supply for those credits. For tractability, we assume this market is competitive and manufacturers are price-takers. Depending on the equilibrium price of the credits, it may be profitable for non-constrained manufacturers to decrease the average fuel consumption through price changes and to collect additional profits from selling the fuel consumption credits. The manufacturers that are not complying make an arbitrage between the implicit cost of complying and the price of the credits.

[5]This is similar to the CO_2 cap-and-trade system where a fixed number of permits to offset emissions −the cap− is allocated among the different polluters. After emissions amounts are realised, producers with an excess of permits can trade them with the producers in deficit. In our case, if a manufacturer is above the standard, it is able to sell a number of credits equivalent to its volume of cars sold times the gap between its mpg fleet average and the standard.

We assume that all manufacturers must comply with the regulation and cannot pay penalties instead.[6] Under a fuel consumption standard with a trading system, the profits of a manufacturer are:

$$\Pi_m = N\left(\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})(p_j - c_j) + \rho\eta_m \sum s_j(\mathbf{p})\right),$$

where ρ is the price of a gallon per 100 miles of fuel consumption traded and η_m represents the manufacturer's net supply of compliance credits. If the manufacturer is a net buyer, η_m is negative. The manufacturer's problem is:

$$\begin{aligned} & \max_{p_{j,j\in\mathcal{J}_m},\eta_m} \Pi_m(\mathbf{p}) \\ \text{s.t.} \quad & e_m(\mathbf{p}) + \eta_m \leq \bar{e}. \end{aligned}$$

Since the price of credits is exogenous to manufacturers, it implies that manufacturers always have an incentive to sell their extra credits.[7] Therefore, in equilibrium, the inequality constraint is binding.

3.4 Insights Into the Comparison of the Policies

We first compare the standard and feebate policies under special cases related to the composition of the manufacturers' fleets and the possibility to pay a penalty in case of non-compliance. Then we present the equivalence between the policies when there is a market for credits of fuel efficiency. Finally, we investigate the difference between simple standards and attribute-based standards. All proofs can be found in Appendix A. The results rely on the assumption that there is a unique equilibrium in prices and shadow costs ($\tilde{\lambda}_m$) under the standard and in prices and feebate parameters ($\tau, \tilde{e}$) under the feebate. We also rely on these two preliminary results:

(i) Under the standard (feebate) regulation prices are increasing in the shadow cost of compliance (feebate rate) for cars with fuel consumption above the standard (feebate pivot point); and conversely for cars with fuel consumption below the standard (feebate). As a consequence, price distortions, i.e $|p_j^{CAFE} - p_j^0|$ (respectively $|p_j^{feebate} - p_j^0|$) are increasing with the shadow cost of compliance (feebate rate).

[6] Allowing manufacturers to pay the penalty instead of complying is equivalent to imposing a cap on the price in the fuel efficiency level market. This complicates the analysis if the market price is higher than the penalty.

[7] We rule out situations where a manufacturer prefers to offer fewer credits in order to increase the market price.

(ii) A manufacturer's average fuel consumption e_m decreases with respect to the shadow cost of compliance $\tilde{\lambda}_m$ (feebate rate τ) under the standard (feebate) regulation.[8]

RESULT 1. **Symmetric manufacturers and compliance.** *Suppose all manufacturers $m = 1, ..., M$ produce the same set of cars and they are initially not complying with the standard ($e_m > \bar{e}$). Suppose also that choosing to pay the fine is not allowed (all manufacturers must comply). Then the equivalent feebate scheme is such that*

1. *the pivot point is $\tilde{e} = \bar{e}$ and*
2. *the feebate rate is $\tau = \tilde{\lambda}_m = \cdots = \tilde{\lambda}_M$ with optimal prices that are identical under both policies.*

This result implies that under this stylized industry configuration the two policies are strictly equivalent and yield the same producer and consumer surplus.

RESULT 2. **Asymmetric manufacturers.** *Assume a market consisting of two manufacturers. Assume that choosing to pay the fine is not allowed. Then*

1. *if the two manufacturers are initially not complying with the standard: $e_m > \bar{e}$, $m \in \{1, 2\}$ and if a firm's shadow cost of compliance is greater (lower) than the industry's average shadow cost, it experiences larger (lower) price distortions under the standard than under its equivalent feebate, and*
2. *if a manufacturer is non-constrained ($e_m < \bar{e}$), the complier experiences larger price distortions under the standard regulation than under the equivalent feebate.*

This result illustrates the advantage of the feebate over the standard when some manufacturers are non-constrained: the former allows for a compensation from the most fuel efficient manufacturers to the least fuel efficient ones. The key difference between the standard and the feebate is that under the standard a non-constrained manufacturer does not have incentives to become more fuel efficient while the feebate offers incentives to all.

RESULT 3. **Optimal decision to pay the fine.** *If there is only one manufacturer, it chooses to pay the fine instead of complying if the penalty is lower than the shadow cost of compliance. If there is more than one manufacturer, the ranking between the shadow cost and the penalty is not enough to determine whether to comply or pay the fine.*

Overall, Results 1-3 illustrate the difficulty to compare theoretically the two policies when we have simultaneously: (i) heterogeneity of manufacturers including some that are non-

[8] We show in Appendix A that these two results hold under some conditions.

constrained, (ii) the possibility to pay fines instead of complying that caps the marginal cost of compliance, and (iii) imperfect competition in the market.

RESULT 4. **Trading system for fuel efficiency.** *Assume mandatory compliance. Allowing manufacturers to trade fuel consumption credits is equivalent to a feebate scheme with revenue neutrality, the pivot point is equal to the standard and the feebate rate* τ *is equal to the price of the fuel consumption credits* ρ.

Allowing manufacturers to trade credits of fuel consumption creates an equivalence between the CAFE and feebate policies. Indeed, trading allows for the same compensation for the fuel inefficient manufacturers by the most efficient ones as under the feebate. It induces non-constrained manufacturers to react directly to the standard because they can increase their profits by being more fuel efficient and selling more credits.

The new U.S. CAFE standards rules also transformed the regulation into an attribute-based standard. This is also similar to the new *mandatory emissions target reductions* regulation in Europe that started in 2015. There, the standard is car-specific: it depends on the value of the attribute. Concretely, we consider the types of standards implemented in the U.S. in which each vehicle has a fuel consumption target ψ_j that is an increasing function of the footprint w_j:

$$\psi_j = \bar{e} + a(w_j - w_0). \tag{4}$$

Recall that $\bar{e}$ is the fuel consumption standard and is measured in gallons per 100 miles and that the footprint is the area obtained by multiplying the length and the width of the car. The parameters of this regulation are a and w_0 with $a > 0$ so that larger cars have higher fuel consumption targets. To keep things simple, we consider w_0 to be the initial fleet average footprint; a is the coefficient of the regression of the car's fuel consumption on the footprint. The manufacturer's constraint is now:

$$\frac{\sum_{j\in\mathcal{J}} s_j(\mathbf{p})e_j}{\sum_{j\in\mathcal{J}} s_j(\mathbf{p})} \leq \frac{\sum_{j\in\mathcal{J}} s_j(\mathbf{p})\psi_j}{\sum_{j\in\mathcal{J}} s_j(\mathbf{p})}.$$

RESULT 5. **Attribute-based standard.** *Relative to the simple standard policy, a footprint-based standard relaxes (tightens) the constraint of a manufacturer that sells cars with an average footprint above (below) the industry's average.*

4 Data and Estimation

To simulate the effect of the two alternative regulations, we use demand parameters (price sensitivity and mean utilities) and marginal costs as inputs. We estimate the demand for cars for France and the U.S. separately using the nested logit specification presented in Section 3.1. We then recover marginal costs assuming the prices observed correspond to the competitive equilibrium described in Section 3.2.

4.1 Data

We use a dataset from the association of French automobile manufacturers (CCFA, Comité des Constructeurs Français d'Automobiles) that contains all the registrations of new cars purchased by households in France between 2003 and 2008. Each year, we observe about one million vehicle registrations that contain the following attributes: brand, model, car-body style, number of doors, horsepower, CO_2 emissions, weight, and fuel energy.[9] These characteristics have been complemented with average annual fuel prices and the average euro-dollar exchange rate to compute the cost of driving in dollars for 100 miles. Prices are also converted from euros to dollars. The monetary variables are deflated to be expressed in constant 2007 dollars.

For the American market we use data on car characteristics and market shares from J.D. Power and Associates (JDPA) and from Ward's Communications covering the period of 2000 through 2007. For each car model we observe the price, weight, horsepower, length, and width. We combine weight and horsepower into a single measure, acceleration, which we define as horsepower divided by weight. Since length and width are highly correlated, we use only length in the demand estimation.[10] Gasoline prices were obtained from the Energy Information Administration. All prices are converted into 2007 dollars using the CPI published by the Bureau of Labor Statistics. For both countries we use annual market shares for the estimation.

CAFE standards in the U.S. exist for two categories of cars: passenger cars and light-duty vehicles. Here we concentrate on the first category as to be able to compare outcomes across the two countries. The standard for the passenger cars category was 27.5 mpg at the time covered by our data. After excluding light-duty vehicles (pickups and SUVs) from the data, we compute the weighted CAFEs for each manufacturer following the harmonic mean definition. These computed CAFEs are consistently below those reported to the NHTSA

[9] In France, 67% of new vehicles are diesel powered. Those vehicles are more fuel efficient than their gasoline counterparts.

[10] In Copeland et al. [2011] there is also a detailed description of this dataset.

[2014]. There are two reasons to explain this: the credits earned from the past three years are added to the final NHTSA reported numbers, and second, the numbers reported to the NHTSA do not match the EPA numbers (which are the ones we use here), because the two agencies have different methods to calculate the CAFEs. This issue in the data has been documented in Klier and Linn [2011].[11] Therefore we find an equivalent CAFE standard of 19.1 mpg that matches the compliance nature of all manufacturers except one in our data with that of the reported status to the NHTSA.[12]

We present summary statistics on the two markets in Tables B.1 and B.2 in Appendix B. The product choice set and the distribution of market shares are not the same across the two markets. For instance, while in France the two largest manufacturers by market share are the domestic brands PSA and Renault (53.1% market share), the two largest manufacturers in the U.S. are GM and Toyota (with a combined market share of 38.6%).[13] Moreover, neither PSA nor Renault has any significant presence in the U.S. market, but GM and Toyota do have non-negligible, albeit small, shares in the French market (5.0% and 6.0%, respectively). Thus, the two markets greatly differ in the distribution of market shares −the U.S. market being much less concentrated than the French market− as well as in the brands offered in each. In terms of average fuel efficiency, the French manufacturers offer a higher fuel efficiency range than the U.S. market, almost by a factor of 2. Moreover, the average standard deviation of mpg within manufacturers in France is around the level of the highest standard deviation for the U.S. This is partly explained by the diesel versions, which are more fuel efficient.

We observe 18 different manufacturers in France and 16 in the U.S. In each market we observe 446 and 430 car models, respectively in 2007. Products are defined by brand, model, and fuel type in France; we consider two versions of the same model to be different if they use different types of fuel, otherwise we aggregate the market shares of the versions and select the characteristics of the most frequently purchased one. For the U.S., cars are defined by their brand and model name since diesel versions are virtually nonexistent. We group cars into segments, five in the U.S. (small, middle, large, luxury, and CUV) and eight in France (supermini, small, large, small MPV, large MPV, executive, sport, and all-road/SUV).

[11]The authors explain that a car with 35 mpg as reported to the NHTSA has a reported 26 mpg according to the EPA. This gives a factor of conversion of 1.36, which is very close to the factor of conversion we find in our data.

[12]BMW is the exception. Its CAFE of 18.9 is slightly below the implied standard of 19.1 and yet is complying according to the NHTSA files. We consider that BMW is a payer in 2007 so that our initial data and manufacturers statuses are consistent with an initial standard of 19.1 mpg.

[13]PSA is the result of the merger between Peugeot and Citroën.

4.2 Estimation

Table 1 presents the results for the demand estimation for the French and U.S. markets. As expected, the price coefficient is negative and the intra-segment correlation σ is between 0 and 1 for both markets. However, the within-segment substitution appears to be more important in France than in the U.S. Fuel cost has a negative and statistically significant coefficient in both markets. Consumers are much more sensitive to fuel cost in France than in the U.S. (-0.21 versus -0.07), which is consistent with the large difference in initial fuel efficiency of the fleet. Weight and horsepower also have coefficients different from zero and have positive signs showing positive valuations for these attributes in the French market. A similar observation applies to the U.S. for the coefficient on acceleration.

Table 1: Demand parameters for the U.S. market

	U.S.		France	
Variable	Parameter	Std err	Parameter	Std err
Price	-0.83^{***}	0.21	-0.76^{***}	0.10
$\log s_{j\|g}$	0.13	0.10	0.30^{***}	0.05
Fuel cost	-0.07^{***}	0.03	-0.21^{***}	0.01
Length	0.01^{*}	0.01		
Acceleration	0.02^{***}	0.01		
Weight			0.79^{***}	0.24
Horsepower			0.31^{***}	0.04
Coupe			-0.42^{***}	0.13
Three doors			-0.05	0.10
Wagon			-0.08	0.09
Intercept	-9.29^{***}	1.23	-5.75^{***}	0.37

Significance levels: $*$: 10% $**$: 5% $***$: 1%

Notes: The price variable is in $10,000, the weight is in 1,000 kilograms and fuel cost is in dollars per 100 miles. Acceleration is equal to horsepower/weight. Year and manufacturer fixed effects are included. The demand model is estimated using 3,383 car-model observations for the U.S. and 2,492 car-model observations for France. $R^2 = 0.22$ in the U.S. and $R^2 = 0.68$ in France.

The average price elasticity in 2007 is -2.5 in the U.S. while it is slightly larger in France with an average of -3.2. These values are consistent with previous studies. For instance, for the U.S., Train and Winston [2007] find an average elasticity of -2.4 and Berry et al. [1995] obtain elasticities between -3.5 and -6.5. For France, D'Haultfœuille et al. [2016] find an average elasticity of -4.5.

We recover marginal costs using the first order conditions presented in Sections 3.2 and

3.3. Since the CAFE standard policy was already in place in the U.S. for the time period of our data set, we take into account the penalties paid by BMW, Mercedes, and Porsche using our equivalent standard of 19.1 mpg. Ford's average fuel economy (19.3 mpg) is slightly above the standard in 2007, nevertheless we consider it to be a complier. To separate Ford's marginal cost from its shadow cost of compliance, we estimate the following equation

$$\hat{c}_{jt} = K + \lambda_{mt}(e_{jt} - \bar{e}) + X_{jt}\gamma + \varepsilon_{jt}$$

where $\hat{c}_{jt}$ are the estimated marginal costs; K is a constant; and X_{jt} contains fuel consumption, acceleration, length, the squared of these covariates, and brand and year fixed effects. λ_{mt} is the shadow cost of the regulation for manufacturer m at time t when the constraint is binding and it is equal to 0 for non-constrained manufacturers and payers. We define the compliers as those manufacturers whose average fuel efficiencies are less than 5% above the standard. They are: Ford in every year except in 2001 and 2006, and Suzuki in 2002 only. We obtain a shadow cost of compliance for Ford in 2007 of $179. Then, the shadow cost is subtracted from the initial marginal cost for Ford. This methodology has been used by Goldberg [1995] to account for binding quotas on imports of Japanese cars and by Byrne [2015] to separate the marginal revenues from the price regulation effect for the cable TV industry.

The demand and cost parameters imply an average markup rate of 42% in the U.S. and 29% in France. In 2007 the initial fuel economy is 40.2 miles per gallon in France while it is only 21.5 in the U.S. The two markets we analyse here differ in multiple dimensions: market power, in consumers' preferences, and in initial fuel efficiency. Introducing the environmental regulations is then likely to have different impacts in the two markets. This is what we explore by conducting simulations in the next section.

5 CAFE vs. Feebates: Policy Simulations

We simulate the introduction of the two environmental policies in France and in the U.S. using market conditions in 2007 following the strategy laid out in Section 3.3. A standard-type policy is defined by two parameters: the value of the standard $\bar{e}$ and the penalty ϕ. The feebate policy parameters τ and $\tilde{e}$ are determined such that the feebate has the same effects as the standard policy on fuel efficiency outcome and tax revenues.

5.1 Benchmark Scenarios

We begin our analysis by simulating the effects of relatively lenient and realistic environmental regulations. We set the value of $\bar{e}$ to a level of 5% above the initial average mpg of the fleet and the penalty ϕ to 300 dollars per mpg above the standard. It is likely that the cost of not complying exceeds the amount of the penalty paid by manufacturers, indeed we believe there are non-monetary costs associated with non-compliance, such as brand image deterioration and negative advertising.[14] Jacobsen [2013] finds that the shadow costs of compliance for passenger cars are higher than the penalty: 52, 373, and 438 dollars per mpg for Ford, Chrysler, and GM respectively, with a mean of 288. Gramlich [2009] estimates an overall value of 347 dollars per mpg. We take a value of $\phi = 300$ which is inspired by these two estimates. These contrast with the estimates in Anderson and Sallee [2011] which are below \$55. These low estimates in compliance costs were obtained using a different approach that relies on the existence of a loophole that spanned for a very short period of time.

We consider three scenarios in the U.S.: increases in either the standard or the penalty and simultaneous increases in both. We also consider the initial CAFE standard in the U.S. and solve for its equivalent feebate scheme. We only have two scenarios for France corresponding to the two values chosen for the penalty (\$55 and \$300 per mpg).

Table 2 shows the outcome of the different scenarios for the standard-type policy and their equivalent feebate schemes. First, in all the scenarios in which the standard increases, the resulting average mpg is lower than the standard. This reflects the fact that most manufacturers prefer to pay the penalty than to comply. The tax revenue depends non-linearly on the value of the penalty. When the penalty amount is increased by about 6 times, the tax revenue increases approximately by a factor of 4.4 in the U.S. and a factor of 2.6 in France. When we set the penalty value to \$300 per mpg, the tax revenue is around 315 million dollars in France and 3.9 billion in the U.S., which mainly reflects the difference between the U.S. and French market sizes: the U.S. market is indeed more than ten times as big as France's.

The initial CAFE standard in the U.S. corresponds to a very low feebate rate (2.9\$/mpg) but a high pivot point (22.7 mpg). Indeed, the pivot point is higher than the standard (19.1 mpg) meaning that some car models that help a manufacturer comply with the policy would actually be taxed under a feebate regulation. For the 5% case, the rates of the equivalent feebate schemes appear to be similar in the U.S. and in France (25\$/mpg and 40\$/mpg when the penalty is set to \$55, and 133\$/mpg and 158\$/mpg when the penalty is set to \$300, respectively). In both countries, the feebate pivot points are always above the value of the standard.

[14]The recent Volkswagen scandal has immediately negatively impacted its sales which have remained stable in October 2015 -despite the increase of manufacturers discounts- as opposed to a global sales increase of 8% according to abcNEWS (see `http://abcnews.go.com/Business/wireStory/diesel-scandal-volkswagens-us-sales-forecast-flat-34662376`).

Table 2: Outcomes and equivalent feebate parameters associated with the benchmark scenarios

	U.S.				France	
Initial average mpg	21.5	21.5	21.5	21.5	40.2	40.2
Standard (mpg)	19.1	22.6	19.1	22.6	42.2	42.2
ϕ ($/mpg)	55	55	300	300	55	300
Results for both policies						
Average mpg	21.5	21.6	21.5	21.8	40.5	41.5
Tax revenue (million $)	39.3	864	174	3,923	123	315
Equivalent feebate parameters						
τ (feebate rate, $/mpg)	2.9	25	14	133	40.0	158
$\tilde{e}$ (pivot point, in mpg)	22.7	24.7	22.8	24.6	43.1	43.2

Notes: For the U.S., the column with a standard of 19.1 mpg corresponds to the case with no increase in the standard, all other columns correspond to a standard equivalent to an increase of 5% on the initial average mpg.

In the U.S. when the penalty is equal to $55, all manufacturers prefer to pay the fine than to comply. When the penalty increases to $300, BMW prefers to comply to the initial standard (19.1 mpg) and its shadow cost is equal to 275 $/mpg. In contrast, when the standard is increased to 22.6 mpg, BMW is better-off by paying the fine. This is because the penalty is relatively low compared to the price of the cars, especially the fuel inefficient ones ($300 corresponds to 1.3% of the average car price in the U.S.). For the same standard of 22.6 mpg, three manufacturers are ex-ante complying with the regulation and are therefore non-constrained (Toyota, Honda, and Kia). Three manufacturers have no car models with a fuel efficiency above the standard: Mercedes, Porsche, and Subaru. These manufacturers are therefore unable to comply with the regulation and automatically belong to the set of payers.

Only one manufacturer in France is ex-ante complier (PSA) and three manufacturers do not produce any vehicle above the standard of 42.2 mpg (Chrysler, Porsche, and Ssangyong). We obtain a total of 14 payers and 3 compliers in France when the penalty is set to $300 while no manufacturer complies for a penalty of $55.

The estimates of the compliers' shadow costs $\tilde{\lambda}_m$ are, for France: 110$/mpg for Fiat, 120$/mpg for Renault, and 200$/mpg for Toyota. We note that these values are lower than the value of the penalty. Indeed, in Section 3.4, we show that the choice of complying versus paying the fine relies partly on a comparison between the value of the penalty and the shadow cost.

We then compare the welfare consequences of the two policies in the U.S. and France. We measure the profits, consumer surplus, and welfare. We display two different measures of welfare: the first is simply defined as the sum of profits, consumer surplus, and tax revenues while the second takes into account the value of avoided CO_2 emissions per year. For the latter, we assume 13,765 miles driven per year for the U.S. and for France we assume that gasoline cars travel 6,284 miles per year and diesel cars travel 10,684 miles per year.[15] We use a social cost of carbon of $36 per ton of carbon emissions.[16] We do not take into account the rebound effect that potentially encourages households to drive more as they buy more fuel efficient vehicles. However, we allow them to drive more when they switch from gasoline to diesel in France.

Consumer surplus is measured according to the following expressions. For each car segment, we compute

$$v_g = (1-\sigma)\log \sum_{j \in \mathcal{J}_g} \frac{\exp(\delta_j)}{1-\sigma}$$

and then aggregate over the segments as follows:

$$CS = \frac{1}{\alpha} \log \big(1 + \sum_g \exp(v_g)\big),$$

where α measures the sensitivity to price and was obtained in the demand estimation. In order to obtain the total consumer surplus in the market we multiply this individual consumer surplus by the number of households.

Table 3: Welfare effects of the two policies for both countries under the benchmark scenarios

	U.S.						France			
	22.6, 55		19.1, 300		22.6, 300		42.2, 55		42.2, 300	
	S	F	S	F	S	F	S	F	S	F
Δ Sales	-0.52	-0.52	-0.12	-0.11	-2.58	-2.48	-0.73	-0.72	-2.8	-2.45
Δ Profits	-0.49	-0.48	-0.07	-0.06	-2.61	-2.46	-0.68	-0.66	-2.56	-2.19
Δ CS	-0.63	-0.63	-0.15	-0.13	-3.14	-3.03	-0.81	-0.8	-3.09	-2.71
Δ CO_2	-0.73	-0.73	-0.2	-0.19	-3.87	-3.78	-1.06	-0.94	-4.3	-3.22
Δ W	-0.23	-0.22	-0.06	-0.05	-1.31	-1.18	-0.32	-0.31	-1.77	-1.39
Δ W w/CO_2	-0.23	-0.22	-0.06	-0.05	-1.29	-1.16	-0.32	-0.31	-1.76	-1.38

Notes: "W" represents welfare gross of emissions. "W w/CO_2" represents welfare net of emissions. We use a value of 36$/t$CO_2$. All numbers are percentage changes. "S" stands for standard and "F" for feebate. The first number at the top of each column is the level of the standard in mpg and the second number is the value of the penalty in $/mpg.

Table 3 provides the variation of sales, profits, consumer surplus, and welfare associated with the introduction of each of the two environmental regulations. We observe that in the

[15] For the U.S. see U.S. Department of Transportation, Federal Highway Administration [2009]. For France, averages were obtained from D'Haultfœuille et al. [2014] who use data from a survey on means of transport conducted in 2007-2008.

[16] U.S. Environmental Protection Agency [2016].

two countries both policies decrease sales, profits, consumer surplus, and welfare. These effects are rather small because we consider a relatively lenient policy. Indeed, both sales and profits decrease by around 2.5 to 2.6% for the 5% and the $300 scenario. The feebate creates less distortions than the standard regulation and less profits and consumer surplus losses. These effects are the consequence of the feebate's ability to redistribute the fuel efficiency levels across manufacturers while the standard regulation forces the redistribution to occur within individual manufacturers. Total CO_2 emissions decrease more under standard policies than under their equivalent feebates. However, this does not have a significant effect on the welfare net of emissions and the feebates always dominate their equivalent standard regulations.[17]

The benefits of redistribution across manufacturers under the feebate are important in both markets since the set of car models offered by each manufacturer is rather homogenous in terms of fuel efficiency. Luxury brands such as BMW, Chrysler, Mercedes-Benz, and Porsche offer very few fuel efficient vehicles and prefer to pay the penalty rather than to comply. Under the feebate regulation, the fuel inefficiency of these manufacturers is compensated by the existence of Toyota and Honda in the U.S. and by Renault and PSA in France. The effects on consumer surplus are rather large because manufacturers exercise high market power and pass-through the penalty to consumers. In the end, welfare losses gross of CO_2 emissions are not very large (between -1.8% for the standard regulation in France and -1.2% for the feebate in the U.S. for the 5% and $300 scenario) because the profits and surplus losses are mitigated by the amount of taxes collected. The tax revenue is large because most of the affected manufacturers prefer to pay the penalty rather than to comply.

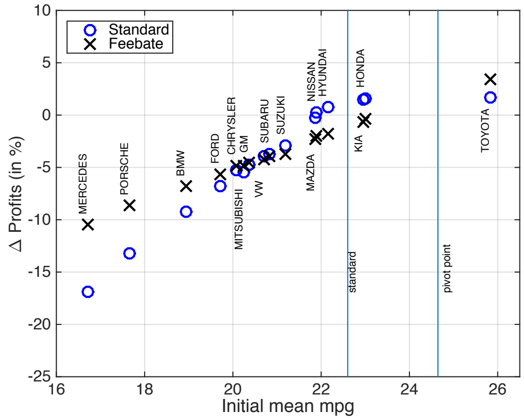
Although the effects on profits at the aggregate level are all negative, they mask heterogeneous effects at the individual manufacturer level. By definition of the feebate regulation, some cars are subsidised, which makes their producers eventually better off. We explore

[17]Our welfare analysis neglects the impacts of the regulations on the used car market in the medium- and long-run. Specifically, if fuel inefficient cars become more expensive under the regulations, their lifetimes increase and this mitigates the fuel efficiency gains. We assess the fuel efficiency in the medium- and long-run using a simplified model for the used car market. Since we do not have data for the used-car market, we assume that each year there is a probability θ_j of scrapping a vehicle of model j as a decreasing function of its price p_j such that $\theta_j = bp_j^{\kappa}$. This closely follows Bento et al. [2009] and Jacobsen [2013]. We assume a lifetime of seven years for all car models if they are not scrapped and an elasticity $\kappa = -2.9$ of the scrap probability with respect to the price. We calibrate the coefficient b such that the probability of scrapping the car is 0.06 with a price equal to the overall average level. In each year, we use the same vector of equilibrium prices (one for each policy) and compute the car model specific probabilities of being scrapped. We do this analysis for the (5%, $300) scenario in the U.S. Similar to Jacobsen [2013], we find that the gains in fuel efficiency are smaller than without accounting for the used car market: 1.06% under the standard and 0.99% under the feebate against 1.3% in the benchmark. We note that the increases in fuel efficiency only differ by 0.07 percentage points across the standard and feebate policies. This suggests that welfare differences would be also small.

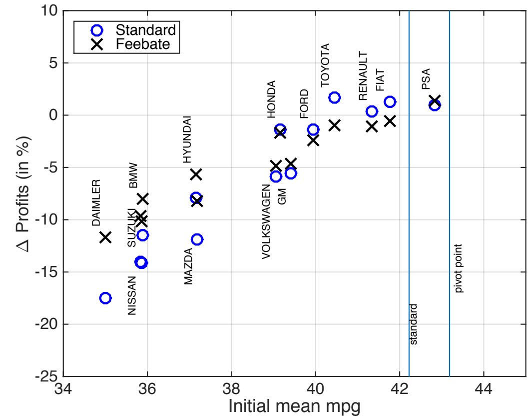
these distributional effects by analysing the variation of profits by manufacturers under both regulations for two levels of stringency: standards that correspond to increases in 5% and 10% of the initial average mpg. The penalty ϕ is set to \$300 in both scenarios.

Figure 1 reveals that the ranking of the two policies is heterogeneous across manufacturers in both countries. In three of the four cases presented, the feebate regulation is preferred at the two extremes of the fuel efficiency spectrum but not so for the intermediate values. Indeed, 8 out of 16 manufacturers in the U.S. and 5 out of 18 in France prefer the standard to the feebate when we consider the standard of 5%. Some manufacturers even increase their profits under the standard-type regulation while those same manufacturers experience losses under the feebate. This occurs because the CAFE standard has very strong effects on the very fuel inefficient manufacturers (Porsche, Mercedes, and BMW for example). The constraint imposed by the regulation leads them to loose market share while the manufacturers that are moderately affected (Hyundai, Honda, and Kia in the U.S.; Toyota, Renault, and Fiat in France) gain market share. Clearly, the profits of those that are non-constrained by the standard (Toyota in the U.S. and PSA in France) increase under the two regulations. Overall the profits increases do not offset the losses of the fuel inefficient manufacturers. The difference of profits under the two regulations is quite large for the fuel inefficient manufacturers when we consider the 5% case. However, under the 10% case, the differences are negligible for most manufacturers in France. This reflects the fact that all manufacturers are constrained by such a level of the standard and only PSA complies. Therefore, the equivalent feebate scheme has a feebate rate close to the penalty (\$269) and a pivot point close to the standard (44.4 mpg against a standard of 43.4 mpg).

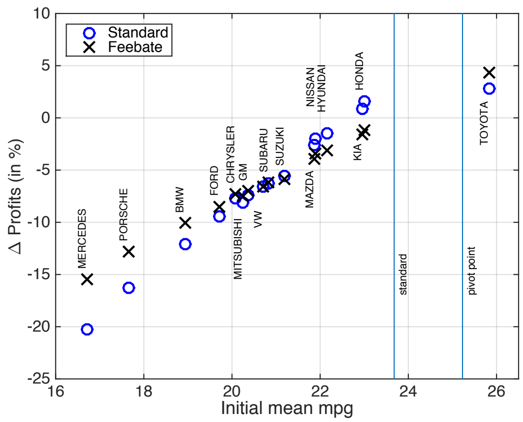
Figure 1: Effects on profits from each policy type by manufacturer



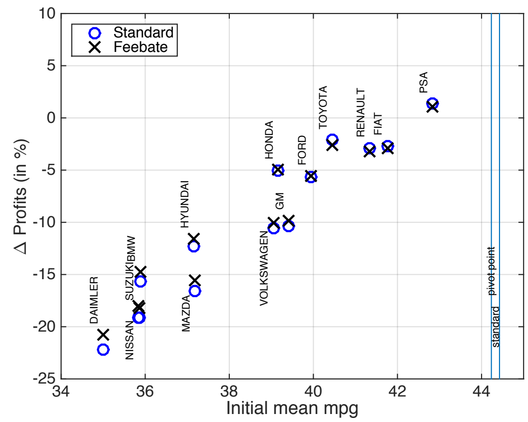
(a) U.S., 5%



(b) France, 5%



(c) U.S., 10%



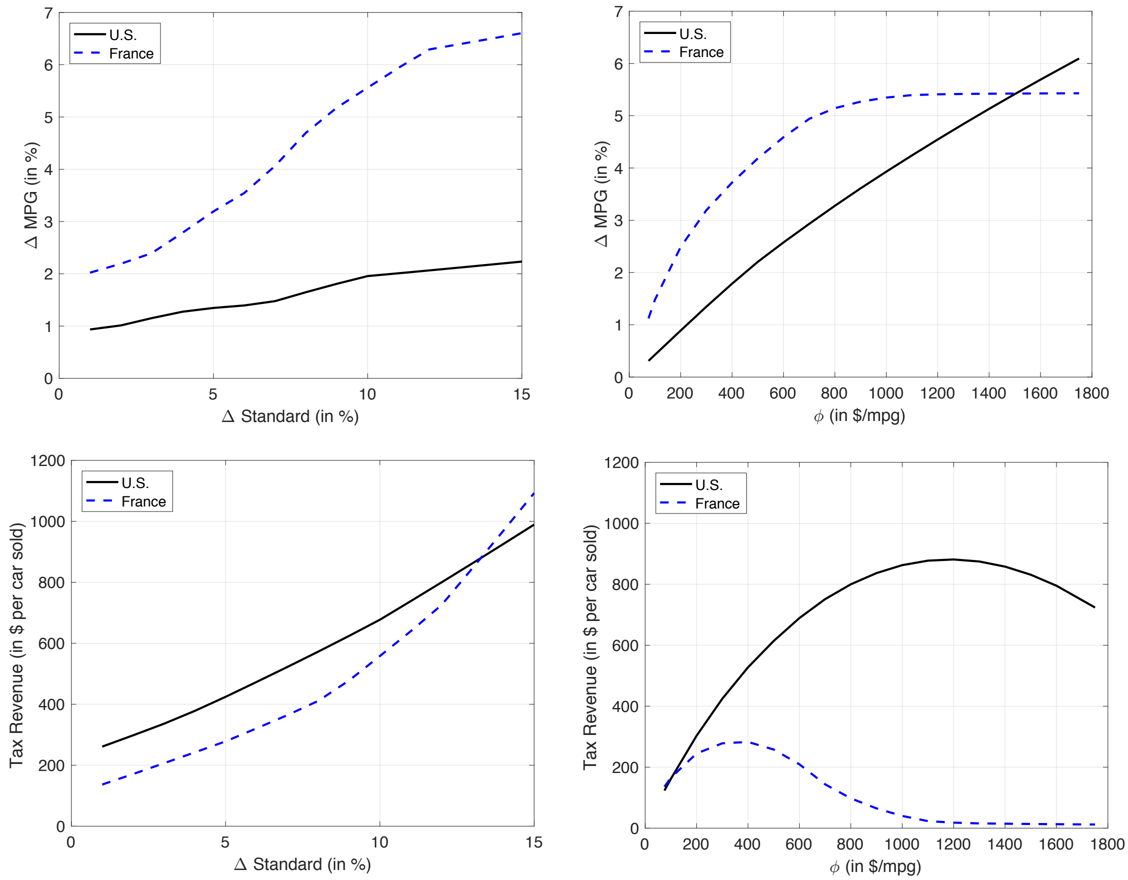
(d) France, 10%

Notes: 1a and 1b present the changes in profits by manufacturer for a standard that corresponds to a 5% increase with respect to the initial average fuel economy of the fleet. Bottom panels 1c and 1d present similar results for an increase of 10%. The vertical lines indicate the level of the standard and the feebate pivot point. For France we omit four manufacturers, Mitsubishi, Chrysler, Ssangyong, and Porsche. Their profits losses are between -75% and -30% under the CAFE, and -54% and -21% under the feebate, both corresponding to the 5% increase of the standard. For the 10% case, profits fall between -79% and -35% under both the standard and the feebate for this set of manufacturers.

5.2 Simulation Analysis for Different Levels of the Regulations

Now we turn our attention to the comparison between the two policies for different levels of policy stringency. First we fix the penalty parameter ϕ at 300 dollars per mpg and vary the standard between 1 and 15%. Then, we keep the standard fixed at 5% and vary the penalty from 75$ to 1,750$. Figures 2 and 3 present the main results. More details are available in Appendix B and C.

Figure 2: Change in mpg and tax revenue amounts by policy instrument and country



Notes: For the first column, $\phi = 300\$/\text{mpg}$. In the second column, the standard is set to 5% above initial mpg.

First, we analyse how the fuel efficiency and the tax revenue change when the policy stringency levels increase, either through an increase in the standard or through an increase in the penalty.

We find that the average mpg increases with the stringency of the standard. The curve of efficiency gains is steeper in France than in the U.S. Increasing the penalty produces steady efficiency gains in the U.S. while its effect in France has a concave curvature: increasing the penalty has virtually no effect above $1,000.

The tax revenue per car sold increases rapidly with respect to the level of the standard, and it is decreasing for high values of the penalty, displaying a bell-shaped curve. This Laffer curve shows that for penalties above 1,200 dollars in the U.S. and 400 dollars in France, the tax revenue decreases. These non-linear effects are the result of the switching status of manufacturers from payer to complier (more details are available in Table B.3 in Appendix B).

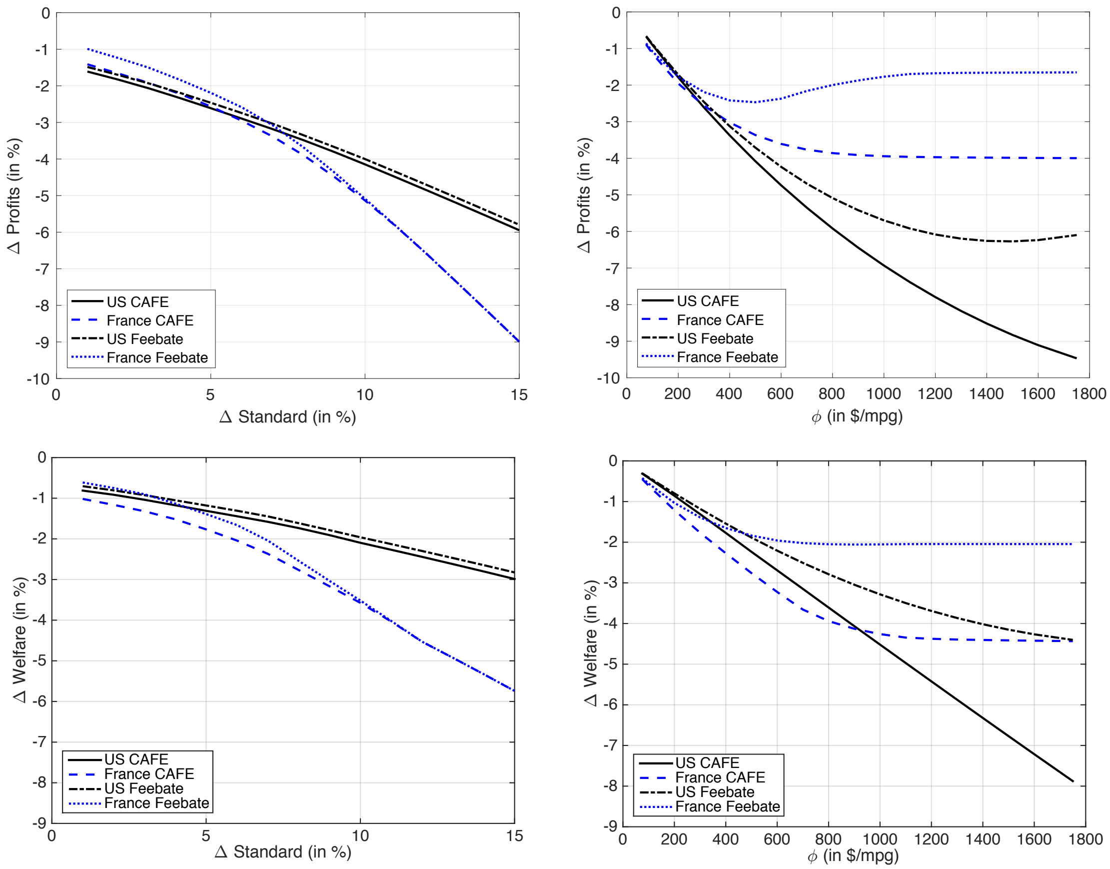
We analyse further the welfare effects of the different levels of regulation in Figure 3. As before, we find that both policies always have negative effects on consumer surplus and profits and both display very similar patterns.[18] In France we observe equal welfare effects for values of the standard of 12% and above. This is because all manufacturers are paying the fine at those levels and the equivalent feebate scheme has a pivot point equal to the standard and a feebate rate equal to the penalty. The average consumer surplus decreases up to 7% in the U.S. and 10% in France for a standard of 15%. The decreases in profits and surplus are steeper in France than in the U.S. Indeed, increasing the standard is a much more effective instrument to improve mpg in France than in the U.S. and it is therefore associated with greater welfare losses. In contrast, the profits and surplus losses are higher in the U.S. when the penalty increases. We also observe a non-monotonic effect of increasing the penalty on the profits and surplus variations under the feebate regulation. This is a consequence of the Laffer curve: less tax revenue is raised under the standard, which implies a more lenient feebate scheme (the equivalent feebate schemes are detailed in Table B.4 in Appendix B).

Figure 3 also shows that the standard policy is associated with greater profits than the feebate policy for all the values considered. The gap between the policies is of small magnitude in the case of an increase in the standard but this gap is larger with increases of the penalty. In addition, losses in profits are larger in France than in the U.S. for values of the standard above 7% whereas for increases in the penalty firms in France experience lower losses than in the U.S. This is a consequence of the fact that the standard is a more effective policy instrument than the penalty to improve fuel efficiency levels in France while the penalty is more effective in the U.S.

Even though the aggregate profits are always lower under the standard than under the feebate in the U.S. and for values of the standard less than 12% in France, this hides heterogeneous effects across manufacturers. Tables in Appendix C provide the number of manufacturers that are better off under the standard than under the feebate. In the U.S. we find that the majority of manufacturers prefer the standard at 5% or below. In France most manufacturers are better off under the feebate except at values 12% and above where the two policies become identical.

[18] See the effects on surplus separately in Figure C.1 in Appendix C.

Figure 3: Profits and welfare changes by policy instrument and country



Notes: For the first column, $\phi = 300\$/\text{mpg}$. In the second column, the standard is set to 5% above initial mpg.

As shown in the same Figure, implementing a standard-type policy leads to larger welfare losses than those seen with a feebate policy, consistent with the previous set of results. For values of the standard regulation above 12% the two policies are strictly equivalent in France since in these cases all manufacturers are payers and the feebate rate is equal to the penalty. The welfare losses from the CAFE standard are on average 1.1 times larger than those under the feebate policy in the U.S. and up to 1.7 times larger than under the feebate in France. This ratio decreases with the level of the standard in both countries.

Gross welfare is about 28.4 billion dollars in France and about 242.5 billion in the U.S. initially. Welfare monotonically decreases as the stringency of the policies increases. The differences in welfare between the two policies are non-negligible: up to 391 million dollars in the U.S. and up to 119 million dollars in France. CO_2 emissions account in most cases for an amount between 0.3 and 0.8% of the gross welfare.

In terms of emissions, the feebate is dominated most of the time by the standard.[19] This is explained in part by a quantity effect, in which the number of vehicles sold is greater under the feebate than under the standard. There is also a fleet composition effect since the average emissions per car is always larger under feebates. Despite the presence of diesel cars in France and the increase of their share with more stringent policy levels, their effect on emissions is small because higher number of miles driven from these vehicles offset the decrease in fuel consumption.

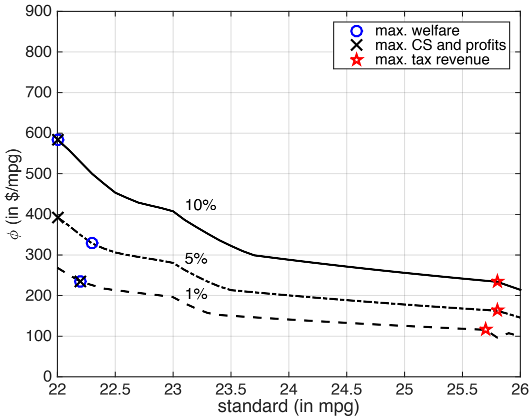
5.3 Trade-off Between the Penalty and the Standard

Under the CAFE-type regulation, both the level of the standard and the penalty can be used by the policy-maker to increase the average fuel efficiency of the fleet. We investigate the trade-off between those two policy parameters. Our framework enables us to find all the combinations that yield the same level of average mpg in the market.

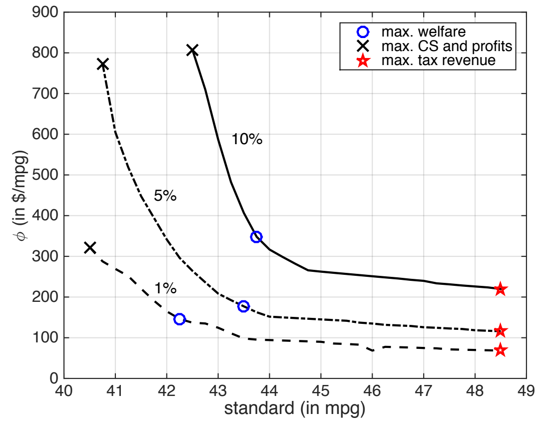
To implement this, we fix the level of fuel efficiency standard and search for the level of the penalty that implements a given target level of average mpg. We carry out this exercise by setting the targets to the average fuel efficiency levels obtained from the standards of 1%, 5%, and 10% above the initial mpg of the fleet. In Figure 4 each line represents the combinations of the two policy parameters that yield the same average fuel efficiency level of the fleet. The downward sloping nature of these curves confirms the trade-off between the two parameters. For each of the targets, we also find the points where consumer surplus, profits, tax revenue, and welfare gross of emissions are maximised. The pattern of the location of maximum consumer surplus and profits is to the left of the curves for all targets except for the lowest target in the U.S. where this point lies slightly to the right. The maximisation of the tax revenue always occurs at the highest values of the standard in France. In the U.S., tax revenue is maximised close to the highest values of the standard considered. In France maximum welfare is obtained in the middle range of the standard and penalty values, whereas in the U.S. these points are found at the lowest levels of the standard.

[19] For the full results on CO_2 emissions, see Figure C.1 in Appendix C.

Figure 4: Combinations of policy parameters for the CAFE standard



(a) U.S.



(b) France

Notes: Each curve is associated with the target of fuel efficiency indicated in mpg which corresponds to the level obtained from the 1, 5, and 10% standards.

5.4 The New 2011 CAFE Standards

Trading of Credits

We investigate the effects of allowing manufacturers to trade fuel efficiency levels in a market for credits. We rule out the possibility to pay the penalty, thus there is no tax revenue $R^{\text{CAFE}} = 0$ and $e^{\text{CAFE}} = \bar{e}$, i.e. the standard is exactly implemented. In Section 3.4 we showed that such a market for credits is strictly equivalent to a feebate with revenue neutrality and where the pivot point $\tilde{e}$ is equal to $\bar{e}$, therefore we only need to solve for the feebate rate τ. The feebate rates are higher than in the benchmark scenario: we obtain \$169 for the U.S. and \$171 for France and \$133 and \$158 when trade is not allowed. The feebate pivot points are lower: 21.8 mpg against 24.6 mpg for the U.S. and 41.5 mpg against 43.2 mpg for France. This implies that fewer cars are subject to a tax and more cars receive the subsidy.

As Table 4 shows, this modified CAFE regulation dominates the basic standard and the feebate in terms of sales, profits, and consumer surplus. This comes at a cost of higher emissions and no tax revenue. Overall welfare losses are the smallest when trading is allowed in both countries.

Table 4: Comparison of the benchmark, the standard with credits, and attribute-based scenarios for the U.S. and France

	U.S.					France				
				AB					AB	
	S	F	ST	S	F	S	F	ST	S	F
Average mpg	21.82	21.82	21.82	21.75	21.75	41.5	41.5	41.5	42.1	42.1
Tax revenue	3,923	3,923	0	3,617	3,617	315	315	0	31	31
Δ Sales	-2.58	-2.48	-0.17	-2.38	-2.3	-2.8	-2.45	-0.77	-2.1	-2.1
Δ Profits	-2.61	-2.46	-0.07	-2.3	-2.22	-2.56	-2.19	-0.46	-1.67	-1.67
Δ CS	-3.14	-3.03	-0.21	-2.9	-2.81	-3.09	-2.71	-0.85	-2.32	-2.32
Δ CO_2	-3.87	-3.78	-1.5	-3.38	-3.3	-4.3	-3.22	-1.55	-1.13	-1.13
Δ W	-1.31	-1.18	-0.16	-1.17	-1.07	-1.77	-1.39	-0.69	-1.94	-1.94
Δ W (w/CO_2)	-1.29	-1.16	-0.15	-1.15	-1.05	-1.76	-1.38	-0.69	-1.95	-1.95

Notes: All numbers are in percentages except for the first two rows. Tax revenues are in millions of dollars. "W" represents welfare gross of emissions. "W w/CO_2" represents welfare net of emissions. We use a value of 36\$/tCO_2. "AB" stands for attribute-based, "S" for standard, "F" for feebate, and "ST" for standard with trading.

Attribute-based Regulation

We model an attribute-based standard that takes a similar form as that in the U.S. and the European Union. In the U.S., the standard is based on the footprint but since this variable is missing we use the length instead and the weight in France. Specifically, each vehicle has a fuel consumption target that is an increasing function of the attribute w_j according to equation (4).

The equivalent feebate scheme has the following form:

$$f_j = \tau \left(e_j - (\tilde{e} + a(w_j - w_0))\right)$$

where w_0 is the sales-weighted mean of the attribute and a is the coefficient obtained from a regression of fuel consumption on the attribute.[20] We keep the values of a and w_0 constant across the standard and feebate policies and solve for the values of τ and $\tilde{e}$ that implement the same average fuel economy and the same tax revenue as before.

Table 4 shows the output for this type of policy in each country. Consistent with our previous findings, the feebate policy causes lower welfare losses than the CAFE standard even with an attribute-based format. It is more difficult to compare the attribute-based standard to the basic standard regulation as the fuel efficiency level attained and tax revenue are different. The attribute-based standard in the U.S. leads to fuel efficiency improvements in between those associated with a simple standard of 2% and 3%. The welfare losses are

[20]In the U.S., $w_0 = 185$ and $a = 0.049$. In France $w_0 = 127$ and $a = 0.01$.

comparable to those of simple standards and feebates. In France, fuel efficiency gains from the attribute-based standard correspond to those from the 8% simple standard. Also, the attribute-based standard and feebate clearly dominate the simple standard of 8% and its equivalent feebate in terms of welfare. This constrasts with Reynaert [2015], who finds that a flat standard is welfare-improving upon an attribute-based standard when manufacturers are forced to comply by modifying prices.

5.5 Extensions

We consider three extensions. The first two consist of specific technological improvements that could be adopted in the short- and medium-run: the imports into the U.S. of models only sold in France and the introduction of hybrid versions of existing models. Lastly we compare our policies against a fuel tax.

Technological Improvements: Imports of European Car Models

In this scenario we make the following assumptions. First, manufacturers import vehicles that are sold in France and not sold in the U.S. (e.g. Mercedes Class A). We allow this only for manufacturers that already sell in both markets. We rule out the possibility to import a more fuel efficient version of an existing car model (e.g. Volkswagen Passat) or a new brand (e.g. Smart). Second, we only allow manufacturers that are directly affected by the standard regulation (i.e. the compliers and the payers) to import new car models. We also restrict the models imported to be those with a gasoline engine and that have an mpg above the standard.[21]

We obtain a total of 44 car models that are eligible under our assumptions (see Table B.5 in Appendix B for the complete listing of the models imported). We further assume that the transportation costs are 10% of the value of marginal costs.[22] We compute the mean utilities of the imported car models using our demand estimates for the U.S. Since the characteristic *length* is missing in the French data, we impute the average length instead. We also set the unobserved characteristics (ξ) to their value in France. We first simulate the new market equilibrium in the U.S. when the 44 new car models are available to consumers in addition to the existing ones.[23] The average predicted price of these imported cars is about $30,000

[21] We only perform this simulation for the U.S. as it is not sensible for manufacturers in France to import American car models that are generally less fuel efficient.

[22] This fraction is inspired by a technical report on costs in the automobile manufacturing industry (see Vyas et al. [2000]).

[23] Manufacturers always have an incentive to import the 44 French vehicles because of the logit nature of the demand model. We checked empirically that these changes have a positive impact on profits relative to the baseline.

in the U.S. market compared to an average of \$27,000 in France. These cars turn out to be on average more expensive in the U.S. than in France because their marginal costs are larger due to the transportation costs.

Table 5: Comparison of the benchmark, the imports, the hybrids, and the gas tax scenarios for the U.S.

	Benchmark		Imports			Hybrids			Gas tax		
	S	F	Initial	S	F	Initial	S	F	T1	T2	T3
Mean mpg	21.82	21.82	21.56	21.86	21.86	21.74	21.98	21.98	21.82	21.55	21.55
Tax revenue	3,923	3,923	38	3,782	3,782	16	3,683	3,683	3,950	647	632
Δ Sales	-2.58	-2.48	0.27	-2.2	-2.1	0.85	-1.3	-1.19	-19.08	-2.45	-2.39
Δ Profits	-2.61	-2.46	0.29	-2.25	-2.1	0.83	-1.42	-1.27	-19.56	-2.49	-2.42
Δ CS	-3.14	-3.03	0.33	-2.68	-2.56	1.05	-1.59	-1.45	-22.39	-2.99	-2.92
Δ CO_2	-3.87	-3.78	0.09	-3.71	-3.61	-0.14	-3.32	-3.22	-28.99	-3.87	-3.78
Δ W	-1.31	-1.18	0.31	-0.95	-0.82	0.95	-0.01	0.13	-19.55	-2.52	-2.46
Δ W (w/ CO_2)	-1.29	-1.16	0.32	-0.93	-0.8	0.95	0.02	0.16	-19.47	-2.51	-2.45
Imports/Hybrids			0.5	0.65	0.57	4.82	5.15	5.6			

Notes: All numbers are in percentages except for the first two rows. Tax revenues are in millions of dollars. "W" represents welfare gross of emissions. "W w/CO_2" represents welfare net of emissions. We use a value of 36\$/tCO_2. "Initial" stands for the initial regulation level, "S" for standard, "F" for feebate. "T1" stands for the gas tax that leads to the same average fuel efficiency (31.6%),"T2" for the gas tax that causes the same reduction in CO_2 emissions as the benchmark standard (3.83%), and "T3" for a gas tax that causes the same reduction in CO_2 emissions as the benchmark feebate (3.74%).

The imports of French car models increase the initial average fuel efficiency by 0.04 mpg relative to the 2007 standard situation as shown in Table 5. Their market share accounts for 0.5%, a rather low level because these cars have characteristics−high fuel efficiency, low horsepower−that are not highly valued by American consumers and their prices are comparable to the average price of already existing cars in the U.S.

With an increase in the standard and its equivalent feebate policy we obtain higher market shares of imports (0.65% and 0.57% respectively). The average fuel efficiency is higher and the tax revenue is smaller compared to the benchmark scenario. Allowing for imports changes Hyundai's status to compliance with a shadow cost of \$207.

The feebate rate is slightly lower (\$134 against \$132) and the pivot point is the same as before (24.6 mpg). The profits, consumer surplus, and welfare losses are lower. Specifically, total welfare (including CO_2 emissions) decreases by 0.93% (versus 1.3% without the imports) under the standard and by 0.8% (versus 1.2%) under the feebate regulation.

Technological Improvements: Introduction of New Hybrid Vehicles

Hybrid vehicles −with both an internal combustion engine and an electric propulsion system-have significantly grown in market share in recent years, up to about 3% in the U.S. in 2015.[24] The success of hybrid vehicles started with the Prius XW10, released at the end of 2000 worldwide. These cars are more fuel efficient than their gasoline only fueled counterparts. For a manufacturer, selling more hybrids can be a strategy to facilitate compliance when the

[24] http://www.afdc.energy.gov/data/10301

standard becomes more stringent.[25] We consider a scenario in which manufacturers with a fleet average above the standard release a hybrid version of their top selling model. This is allowed only for manufacturers that do not have any hybrid model in their fleet. Those models are listed in Table B.6 in Appendix B.

We make the following assumptions for the characteristics of these new hybrid models: the fuel efficiency (in mpg) increases by 70%, the marginal cost increases by 50%, and the horsepower decreases by 25%. These are roughly the average ratios of the current hybrid models' characteristics and their corresponding non-hybrid versions' characteristics in the U.S.

Table 6: Compliers' shadow costs under the benchmark and hybrids scenarios (in $/mpg)

	France	
Manufacturer	Benchmark	Hybrid
Fiat	110	
Ford		157
Renault	120	62
Toyota	200	202

Releasing new hybrid models appears to be an effective solution to remove the constraint imposed by the regulations: six manufacturers are non-constrained by the standard in the U.S. as opposed to the benchmark scenario in which only Toyota is non-constrained. This manufacturer does not take advantage of this technological improvement because it already has hybrid models in its fleet. In France, Fiat joins PSA in the non-constrained manufacturers set and Ford is now a complier (see Table 6). Renault's shadow cost of compliance is reduced by half while Toyota's slightly increases because this manufacturer already had hybrid vehicles in its fleet and its competitors become less constrained. The equivalent feebate schemes are barely affected, in the U.S. the pivot point marginally decreases whereas in France the feebate rate decreases by $21 but the pivot point slightly increases (43.31 against 43.19 mpg).

Assuming that our two policies encourage the introduction of more hybrid models, we find the feebate to be welfare-improving in both countries. In terms of emissions, the effects are different in each country: at the initial level of the policy there is a decrease of 0.14% in the U.S. whereas in the no policy scenario in France emissions are reduced by 6.83% (see Tables 5 and 7.

The modest decrease in the U.S. is explained by the increase in aggregate sales which partly compensates for the increase in fuel efficiency. The pronounced reduction in France is

[25]For instance, in March 2016 Porsche announced that all its car models will be available in a hybrid version, including the Porsche 911. Also in 2016, BMW released the 330e, a hybrid version of the Series 3.

due to two factors: (i) the fuel efficiency gains in France are larger than in the U.S. and (ii) French consumers drive less in average than their American counterparts so the increase in sales does not translate into a large increase in emissions.

Table 7: Comparison of the benchmark, the hybrids, and the gas tax scenarios for France

	Benchmark		Hybrids			Gas tax		
	S	F	Initial	S	F	T1	T2	T3
Mean mpg	41.5	41.5	40.47	41.64	41.64	41.5	40.35	40.32
Tax revenue	315	315	0	272	272	149	23	17
Δ Sales	-2.8	-2.45	1.19	-1.26	-0.87	-31.74	-3.81	-2.85
Δ Profits	-2.56	-2.19	1.06	-1.21	-0.81	-32.08	-3.87	-2.9
Δ CS	-3.09	-2.71	0	-1.4	-0.96	-33.96	-4.2	-3.15
Δ CO_2	-4.3	-3.22	-6.83	-11.35	-11.04	-35.12	-4.3	-3.22
Δ W	-1.77	-1.39	0.43	-0.36	0.06	-32.67	-3.99	-2.99
Δ W (w/ CO_2)	-1.76	-1.38	0.46	-0.32	0.09	-32.66	-3.99	-2.99
% Hybrids			2.28	3.02	2.86			

Notes: All numbers are in percentages except for the first two rows. Tax revenues are in millions of dollars. "W" represents welfare gross of emissions. "W w/CO_2" represents welfare net of emissions. We use a value of 36\$/tCO_2. "Initial" stands for the initial situation without policy, "S" for standard, "F" for feebate. "T1" stands for the gas tax that leads to the same average fuel efficiency (14.5%),"T2" for the gas tax that causes the same reduction in CO_2 emissions as the benchmark standard (1.5%), and "T3" for a gas tax that causes the same reduction in CO_2 emissions as the benchmark feebate (1.11%).

Comparison with a Fuel Tax

In the broader context of environmental regulation, we compare our two policies against a simple fuel tax. Specifically, we solve for the fuel tax levels that yield the same average fuel efficiency as the CAFE standard and feebate and the same reduction in total CO_2 emissions. We assume the same taxation rate for diesel and gasoline.[26] We set the elasticity of driving with respect to gas prices at -0.35 in both countries.[27] To obtain the same average fuel efficiency, we need to impose a fuel tax of 31.6% in the U.S. and 14.5% in France. The tax levels are very high because the choice of car model is not very sensitive to gas prices. Furthermore, there is a large difference in the sensitivity to the cost of driving across countries; French consumers react much more to higher fuel prices than the American consumers. Note however that the gas price in the U.S would still be lower than the fuel prices in France which are initially about twice as high. Since both the standard and feebate regulations

[26] Taxation rates are actually different for diesel and gasoline in France but here we consider an additional uniform tax on the final prices.

[27] See for instance Parry and Small [2005] and Parry et al. [2007].

imply different CO_2 emissions reduction levels, we solve for the fuel taxes that equalize both levels. We find 3.8% and 3.7% for the U.S. and 1.5% and 1.1% for France. Once again, the equivalent tax levels are lower in France because there consumers are more sensitive to the cost of driving. Outcomes of the gas tax equivalent scenarios are displayed in Tables 5 and 7. These equivalent taxes put in perspective our findings on welfare changes under the feebate and the CAFE standard.

6 Conclusion

We develop a framework to make comparisons between CAFE and feebate policies. We constrain the fuel efficiency outcome and the tax revenue to be identical under the two alternative regulations, and measure the effects on profits and consumer surplus. We consistently find that feebate policies welfare-dominate CAFE standard policies for both countries and for different levels of stringency. At a disaggregate level, however, more manufacturers are better off under the fuel economy standard than under the feebate.

This analysis focuses on short-term equilibrium effects, where only prices and demand change after the introduction of a new regulation. However, it is likely that the two environmental regulations provide incentives for manufacturers to modify their fleet composition, either to avoid the constraint of the standard or to take advantage of the rebate in the feebate case. These medium- and long-run effects include the introduction of new car models, the modification of the characteristics of existing models, and mergers with more fuel efficient manufacturers. Our work could serve as the basis for these and other extensions.

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Appendix A: Comparing the Policies

Computational Details

Our objective is to simulate and compare the effects of the two policies described in the main text by keeping the environmental outcome and the tax revenue identical. We accomplish this by first fixing the fuel economy standard $\bar{e}$ and the penalty ϕ. We then solve for the optimal reaction of the manufacturers and the new equilibrium prices and market shares. We obtain the environmental outcome, which is the average mpg attained, and the tax revenue, which is the total amount of fines paid by manufacturers. In a second step, we use these outcome values as input for the feebate policy and solve for the feebate scheme parameters (τ and $\tilde{e}$) that implement the same outcome together with optimal prices.

Solving the system of first order conditions to obtain the new equilibrium prices is challenging for two reasons. First, in the standard-type regulation, manufacturers have the choice to comply or to pay the penalty which introduces discontinuities in the reaction functions of manufacturers. Second, the system of equations defining optimal solutions for new prices under the two regulations is non-linear because prices enter the market share function, which has a logit form, and its derivatives. Thus, there is no closed form solution for prices and we have to use numerical methods to solve for them.

In order to obtain an initial guess for the prices, and to identify the status of each manufacturer, we consider an approximated solution for optimal prices that only depends on initial prices and the car's fuel consumption.

$$\begin{array}{ll} p_j^* = p_j^0 + \lambda_m \frac{(e_j - \bar{e})}{\sum s_j} & \text{if the manufacturer is a complier,} \\ p_j^* = p_j^0 + \phi(e_j - \bar{e}) & \text{if the manufacturer is a payer,} \\ p_j^* = p_j^0 & \text{if the manufacturer is non-constrained.} \end{array}$$

For the simulation of the feebate policy, the approximated expression for optimal prices is

$$p_j^* = p_j^0 + \tau(e_j - \tilde{e})$$

where p_j^0 is the initial price of car model j. This amounts to make the following approximation:

$$\left[\mathbf{\Omega}^{-1}(\mathbf{p}^*)S(\mathbf{p}^*)\right]_j = \left[\mathbf{\Omega}^{-1}(\mathbf{p^0})S(\mathbf{p^0})\right]_j.$$

In other words, this approximation implies that the markup term does not change because of the regulation and the cost of the regulation is entirely passed-through to the prices.

We use this simplified problem to solve for the status of manufacturers in the standard-type regulation environment and to get a good starting point to solve for the entire problem.

In order to determine the manufacturers status, we start by solving the simplified problem assuming all the manufacturers are compliers (except those that cannot comply when they do not sell any vehicle below the standard). Then for each manufacturer, from the most affected to the least affected (this is measured by the $\tilde{\lambda}_m$s), we can see whether it would be better off to unilaterally deviate and pay the fines instead of complying. As we go down the list, the statuses get updated. There might be multiple feebate schemes (τ, $\tilde{e}$) that achieve the same tax revenue and fuel efficiency level. We select only feebates for which the pivot point is the closest to the standard.

Proofs

Proof of the preliminary results. We provide the proof in the case of the standard, the same logic applies for the feebate regulation.

Let $f(\tilde{\lambda}, \mathbf{p}) = 0$ be the vector-valued function that represents the first order conditions $\mathbf{s}(\mathbf{p}) - \mathbf{\Omega}(\mathbf{p})(\mathbf{c} + \tilde{\lambda}(\mathbf{e} - \bar{\mathbf{e}})) + \mathbf{\Omega}(\mathbf{p})\mathbf{p} = \mathbf{0}$. Recall that the element (i, j) of $\mathbf{\Omega}$ is $\frac{\partial s_j}{\partial p_i}$ if i and j belong to the same manufacturer and zero otherwise, assume the value of these derivatives fixed. If the matrix Df_p (defined below) is invertible at a point $(\tilde{\lambda}, \mathbf{p})$ then, by the implicit function theorem, there exists a function g such that $\mathbf{p} = g(\tilde{\lambda})$ at that point and the effect of a change of $\tilde{\lambda}$ on $\mathbf{p}$ is $D_g = -(Df_p)^{-1}Df_{\tilde{\lambda}}$.

$Df_{\tilde{\lambda}}$ is a column vector where the j-th entry is equal to the derivative of the j-th first order condition with respect to $\tilde{\lambda}$: $-\sum_l \frac{\partial s_l}{\partial p_j}(e_l - \bar{e})$. Df_p is a $J \times J$ matrix where the entry (j, l) is equal to the derivative of the j-th FOC with respect to p_l: $\frac{\partial s_j}{\partial p_l} + \frac{\partial s_l}{\partial p_j}$. The first term forms a diagonally dominant matrix.[28] The second term is the first term multiplied by the ownership matrix and it is also diagonally dominant.[29] Therefore, by ignoring the off-diagonal terms, which are quadratic terms of market shares in both matrices, their sum is the diagonal matrix $2 \times diag\left(\left[\frac{\partial s_j}{\partial p_j}\right]\right)$. Then, the j-th entry of the vector-valued function D_g is

$$\frac{\partial p_j}{\partial \tilde{\lambda}} = -\frac{-\sum_l \frac{\partial s_l}{\partial p_j}(e_l - \bar{e})}{2\frac{\partial s_j}{\partial p_j}} = \frac{1}{2}(e_j - \bar{e}) + \frac{\sum_{l \neq j} \frac{\partial s_l}{\partial p_j}(e_l - \bar{e})}{2\frac{\partial s_j}{\partial p_j}} = \frac{1}{2}(e_j - \bar{e}) + \mathcal{O}(s_.). \tag{5}$$

The symbol $\mathcal{O}(s_.)$ represents all the terms that depend linearly or on higher powers of market shares. To see this is the case, we used the expressions of partial derivatives for our nested

[28] The sum of all market shares including that of the outside option is 1, then by taking the derivative with respect to one of the prices we get $\sum_{l=0}^{J} \frac{\partial s_l}{\partial p_j} = 0$. Since $\frac{\partial s_j}{\partial p_j} < 0$ and $\frac{\partial s_l}{\partial p_j} \geq 0$ for $l \neq j$, by removing the term from the outside good we must have $\sum_{l=1}^{J} \frac{\partial s_l}{\partial p_j} < 0$ or simply $\sum_{l \neq j}^{J} \frac{\partial s_l}{\partial p_j} < -\frac{\partial s_j}{\partial p_j}$.

[29] By multiplying by the ownership matrix, there are fewer positive terms in each row, which preserves the inequality for diagonal dominance.

logit demand model:

$$\frac{\partial s_l}{\partial p_j} = \begin{cases} -\alpha s_l \left(\frac{1}{1-\sigma} - \frac{\sigma}{1-\sigma} s_{l|g} - s_l\right) \text{ for } j = l, \\ \alpha s_j \left(\frac{\sigma}{1-\sigma} s_{l|g} + s_l\right), \text{ for } l \text{ and } j \text{ in the same nest, and} \\ \alpha s_j s_l \text{ otherwise,} \end{cases}$$

and observe that if l and j are in the same nest the fraction $\frac{\partial s_l}{\partial p_j} / \frac{\partial s_j}{\partial p_j}$ is

$$\frac{\sigma s_{l|g} + (1-\sigma) s_l}{-1 + \sigma s_{j|g} + (1-\sigma) s_j} \leq \frac{\max\{s_{l|g}, s_l\}}{-1 + \sigma s_{j|g} + (1-\sigma) s_j}$$

since $\sigma \leq 1$. In the case where j and l are in different nests we have

$$\frac{(1-\sigma) s_l}{-1 + \sigma s_{j|g} + (1-\sigma) s_j}.$$

In both cases we obtain an expression that resembles the function $\frac{x}{x-1}$ which has a Taylor expansion around zero equal to $-x - x^2 - x^3 - \cdots$. Since powers of market shares are no greater than the linear term, we assume that those fractions are $\mathcal{O}(s_.)$. These are the factors that multiply each of the terms $\frac{1}{2}(e_l - \bar{e})$ in the sum above.

Since market shares are very small in our setting (we have outside good market shares of 67% and 81% and 430 and 446 products in the U.S. and France, respectively) $\mathcal{O}(s_.)$ is also very small and the term $\frac{1}{2}(e_j - \bar{e})$ dominates.

Therefore, $\frac{\partial p_j}{\partial \tilde{\lambda}} \approx \frac{1}{2}(e_j - \bar{e})$ and the variation in prices $p_j^{\text{CAFE}} - p_j^0 \approx \frac{\tilde{\lambda}}{2}(e_j - \bar{e})$, which indicates that price distortions increase with $\tilde{\lambda}$.

We also have that,

$$\frac{\partial s_j}{\partial \tilde{\lambda}} = \sum_{l \in \mathcal{J}} \frac{\partial s_j}{\partial p_l} \frac{\partial p_l}{\partial \tilde{\lambda}} = \frac{\partial s_j}{\partial p_j} \times \left(\frac{1}{2}(e_j - \bar{e}) + \mathcal{O}(s_.)\right) + \sum_{l \neq j} \frac{\partial s_j}{\partial p_l} \times \left(\frac{1}{2}(e_l - \bar{e}) + \mathcal{O}(s_.)\right)$$

$$\approx \frac{1}{2} \frac{\partial s_j}{\partial p_j} (e_j - \bar{e})$$

since, as before, $\frac{\partial s_j}{\partial p_j}$ dominates the terms $\frac{\partial s_j}{\partial p_l}$ for $l \neq j$. Therefore, $\frac{\partial s_j}{\partial \tilde{\lambda}}$ has the opposite sign of $e_j - \bar{e}$.

Finally, observe that

$$\frac{\partial e_m}{\partial \tilde{\lambda}} = \frac{\sum (e_j - e_m) \frac{\partial s_j}{\partial \tilde{\lambda}}}{\sum s_j} \approx \frac{\sum (e_j - e_m)(e_j - \bar{e}) \frac{\partial s_j}{\partial p_j}}{2 \sum s_j}$$

where in the last expression we used the approximation found for $\frac{\partial s_j}{\partial \tilde{\lambda}}$ above and all the sums are over $j \in \mathcal{J}_m$. Since compliers have a fuel consumption meeting the standard exactly,

$e_m = \bar{e}$ and:

$$\frac{\partial e_m}{\partial \tilde{\lambda}} \approx \frac{\sum (e_j - \bar{e})^2 \frac{\partial s_j}{\partial p_j}}{2 \sum s_j} < 0.$$

A similar result can be obtained for $\frac{\partial e_m}{\partial \tau}$ by replacing the shadow cost $\tilde{\lambda}$ with the feebate rate τ and the standard $\bar{e}$ with the pivot point $\tilde{e}$.

Proof of RESULT 1

Under the standard regulation, the market equilibrium consisting of prices $p_1, ..., p_J$ and shadow costs $\lambda_1, ..., \lambda_m$ satisfies the system of equations

$$\begin{cases} p_k = c_k + \lambda_m \frac{e_k - \bar{e}}{s_m(\mathbf{p})} - [\mathbf{\Omega}^{-1}(\mathbf{p}) S(\mathbf{p})]_k & \forall k \in \mathcal{J}_m, \quad m = 1, ..., M \\ \frac{\sum_{j \in \mathcal{J}_m} e_j s_j(\mathbf{p})}{s_m(\mathbf{p})} = \bar{e} & \forall m = 1, ..., M \end{cases}$$

where $S(\mathbf{p})$ and $\mathbf{\Omega}(\mathbf{p})$ are defined by the demand equations and $s_m = \sum_{j \in \mathcal{J}_m} s_j$ is the sum of manufacturer m's market shares.

Since all manufacturers are identical to each other, $\lambda_1 = \cdots = \lambda_m \equiv \lambda$ and $s_1(\mathbf{p}) = ... = s_M(\mathbf{p}) \equiv s(\mathbf{p})$.[30] Furthermore, in equilibrium each manufacturer's average fuel consumption e_m is equal to the standard so that the average fuel efficiency of the market is also equal to $\bar{e}$ and the equilibrium $(p_1, ..., p_J, \lambda)$ is a solution to the simplified system of equations:

$$\begin{cases} p_k = c_k + \lambda \frac{e_k - \bar{e}}{s(\mathbf{p})} - [\mathbf{\Omega}^{-1}(\mathbf{p}) S(\mathbf{p})]_k & \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e}. \end{cases}$$

Under the equivalent feebate regulation, the equilibrium prices $p_1, ..., p_J$ and feebate parameters $(\tau, \tilde{e})$ satisfy the system of equations:

$$\begin{cases} p_k = c_k + \tau(e_k - \tilde{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p}) S(\mathbf{p})]_k & \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e} \\ \sum_{j=1}^J \tau s_j(\mathbf{p})(e_j - \tilde{e}) = 0. \end{cases}$$

The last equation represents the zero tax revenue condition and combining it with the fuel consumption outcome equation (second line) implies that $\tilde{e} = \bar{e}$. The system of equations that define $(p_1, ..., p_J, \tau)$ simplifies to:

$$\begin{cases} p_k = c_k + \tau(e_k - \bar{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p}) S(\mathbf{p})]_k & \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e}. \end{cases}$$

[30] We rule out asymmetric equilibria as the symmetric equilibrium exists and we assumed uniqueness of equilibrium.

We can make a change of variable and define $\tilde{\tau} = \tau s(\mathbf{p})$ and solve for $(p_1, ..., p_J, \tilde{\tau})$ such that:

$$\begin{cases} p_k = c_k + \tilde{\tau}\frac{(e_k - \bar{e})}{s(\mathbf{p})} - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e}. \end{cases}$$

This system of equations is identical to the system of equations obtained for the standard regulation. By the assumption of a unique equilibrium, the two policies lead to the same prices and the feebate parameter τ is equal to $\frac{\lambda}{s(\mathbf{p})}$.

Proof of RESULT 2.1

Consider firm 1 and firm 2 with shadow costs of compliance $\tilde{\lambda}_1 = \lambda_1/s^{(1)}, \tilde{\lambda}_2 = \lambda_2/s^{(2)}$ such that $\tilde{\lambda}_2 < \tilde{\lambda}_1$, where $s^{(1)}$ and $s^{(2)}$ are the manufacturers' total market shares. e_1^s and e_2^s denote their fuel consumption averages under the standard and are exactly equal to $\bar{e}$.

The feebate scheme that implements the same fuel consumption outcome and tax revenue is $\tilde{e} = \bar{e}$ and $\tau \in (\tilde{\lambda}_2, \tilde{\lambda}_1)$.[31]

Indeed, if $\tau = \tilde{\lambda}_2$, $e_1^f > e_1^s = \bar{e}$ and $e_2^f = e_2^s = \bar{e}$, where e_1^f and e_2^f denote the fuel consumption averages under the feebate. Thus, the feebate generates a fleet average fuel consumption which is above the one from the standard. Conversely, if $\tau = \tilde{\lambda}_1$, $e_1^f = e_1^s = \bar{e}$ and $e_2^f < e_2^s = \bar{e}$. Thus, the feebate implements an average fuel consumption which is below the one from the standard. This is why the feebate rate τ that implements the exact same average fuel consumption is between $\tilde{\lambda}_2$ and $\tilde{\lambda}_1$. Since price distortions are increasing in the shadow cost and the feebate rate (see preliminary result), Firm 1's prices have larger distortions under the standard than under the feebate and conversely for Firm 2.

Proof of RESULT 2.2

Assume now that one of the two manufacturers is non-constrained, $e_2^s < \bar{e}$. Under the standard, $e_1^s = \bar{e}$ and the average fuel consumption e^{CAFE} is between e_2^s and $\bar{e}$. To obtain the same fuel consumption outcome under the feebate, we must have $\tau < \tilde{\lambda}_1$. Indeed, if $\tau \geq \tilde{\lambda}_1$, $e_1^f \leq \bar{e}$ and $e_2^f < e_2^s$ so the average fuel consumption is below e^{CAFE}. Since price distortions are increasing in the shadow cost and the feebate rate (see preliminary result), price distortions for compliers are lower under the feebate than under the standard.

Proof of RESULT 3

Case 1 - Single manufacturer. Under compliance, the optimal prices $p_k, k \in \mathcal{J}_m$ and its

[31] As in the previous proof, $\tilde{e} = \bar{e}$ since we have no tax revenue by forcing manufacturers to comply.

adjusted shadow cost of compliance $\tilde{\lambda}$ are:

$$\begin{cases} p_k = c_k + \tilde{\lambda}(e_k - \bar{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k \in \mathcal{J}_m \\ \frac{\sum_{j\in\mathcal{J}_m} e_j s_j(\mathbf{p})}{\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})} = \bar{e} \end{cases}$$

and if the manufacturer chooses to pay the fine, optimal prices satisfy:

$$p_k = c_k + \phi(e_k - \bar{e}) - \left[\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})\right]_k \forall k \in \mathcal{J}_m$$

If the policy instrument is $\phi = \tilde{\lambda} = \lambda/s$, then the two systems of equations are identical under the two statuses. By uniqueness of equilibrium, the prices are identical. If $\phi > \tilde{\lambda}$ then the prices are more distorted by paying the fine (see preliminary result) therefore the manufacturer prefers to comply.

Case 2 - Multiple manufacturers. Let $\omega_k = -[\mathbf{\Omega}^{-1}S]_k$ be the margin for product k. We use the superindices *comp* and *payer* to denote the complier and the payer status respectively. Profits for manufacturer m under compliance are

$$\begin{aligned} \Pi_m^{comp} &= \sum_{k\in\mathcal{J}_m} s_k^{comp}(p_k^{comp} - c_k) \\ &= \sum_{k\in\mathcal{J}_m} s_k^{comp}(c_k + \tilde{\lambda}_m(e_k - \bar{e}) + \omega_k^{comp} - c_k) \\ &= \sum_{k\in\mathcal{J}_m} s_k^{comp}\omega_k^{comp} + \underbrace{\tilde{\lambda}_m \sum_{k\in\mathcal{J}_m}(s_k e_k - s_k \bar{e})}_{=0 \text{ because of compliance}}. \end{aligned}$$

Profits when it is a payer are:

$$\begin{aligned} \Pi_m^{payer} &= \sum_{k\in\mathcal{J}_m} s_k^{payer}(p_k^{payer} - c_k) - \sum_{k\in\mathcal{J}_m} s_k^{payer}\phi(e_m - \bar{e}) \\ &= \sum_{k\in\mathcal{J}_m} s_k^{payer}(\phi(e_k - \bar{e}) + \omega_k^{payer}) - \sum_{k\in\mathcal{J}_m} s_k^{payer}\phi(e_m - \bar{e}) \\ &= \sum_{k\in\mathcal{J}_m} s_k^{payer}\omega_k^{payer} + \underbrace{\sum_{k\in\mathcal{J}_m} s_k^{payer}\phi(e_k - \bar{e}) - \sum_{k\in\mathcal{J}_m} s_k^{payer}\phi(e_m - \bar{e})}_{=0}. \end{aligned}$$

Both expressions for profits do not depend directly on $\tilde{\lambda}_m$ or ϕ but only through their effects on market shares and margins. The magnitude of these effects depends on the substitution patterns between products and strategic interactions. Therefore the comparison between the two profits is context specific.

Proof of RESULT 4

Under the standard with trading, optimality conditions for car prices are:

$$p_k = c_k + \rho(e_k - \bar{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k = 1, ..., J$$

and the equilibrium price of credits ρ is such that the sum of the credits demanded is equal to the number of credits supplied:

$$\begin{aligned} & \textstyle\sum_m s_m(\mathbf{p}) \left(\frac{\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})e_j}{\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})} - \bar{e} \right) = 0 \\ \Rightarrow \; & \textstyle\sum_m \left(\sum_{j\in\mathcal{J}_m} s_j(\mathbf{p})e_j - s_m(\mathbf{p})\bar{e} \right) = 0 \\ \Rightarrow \; & \textstyle\sum_{j=1}^J s_j(\mathbf{p})\,(e_j - \bar{e}) = 0 \\ \Rightarrow \; & \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e}. \end{aligned}$$

The equilibrium prices of cars $p_1, ..., p_J$ and price of credits ρ under the standard with trading satisfy the following system of equations:

$$\begin{cases} p_k = c_k + \rho(e_k - \bar{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e}. \end{cases}$$

Under the feebate regulation with revenue neutrality, the equilibrium prices $p_1, ..., p_J$ and feebate parameters $(\tau, \tilde{e})$ satisfy the system of equations:

$$\begin{cases} p_k = c_k + \tau(e_k - \tilde{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e} \\ \sum_{j=1}^J \tau s_j(\mathbf{p})(e_j - \tilde{e}) = 0 \end{cases}$$

The two last equations imply that $\tilde{e} = \bar{e}$. The system of equations that define $(p_1, ..., p_J, \tau)$ simplifies to:

$$\begin{cases} p_k = c_k + \tau(e_k - \bar{e}) - [\mathbf{\Omega}^{-1}(\mathbf{p})S(\mathbf{p})]_k \quad \forall k = 1, ..., J \\ \frac{\sum_{j=1}^J e_j s_j(\mathbf{p})}{\sum_{j=1}^J s_j(\mathbf{p})} = \bar{e} \end{cases}$$

Therefore, the two systems of equations that we obtain for the standard with trading and the feebate are identical. By the uniqueness of the solution to each system of equations, we have $\tau = \rho$, the equilibrium prices $p_1, ..., p_J$ are identical and we have full equivalence of the two policies.

Proof of RESULT 5

The constraint of a complier m under the footprint-based standard is:

$$\begin{aligned} \frac{\sum_{j\in\mathcal{J}_m} s_j e_j}{\sum_{j\in\mathcal{J}_m} s_j} &= \frac{\sum_{j\in\mathcal{J}_m} s_j \psi_j}{\sum_{j\in\mathcal{J}_m} s_j} \\ \frac{\sum_{j\in\mathcal{J}_m} s_j e_j}{\sum_{j\in\mathcal{J}_m} s_j} &= \frac{\sum_{j\in\mathcal{J}_m} s_j (\bar{e} + a(w_j - w_0))}{\sum_{j\in\mathcal{J}_m} s_j} \end{aligned}$$

$$\Rightarrow \underbrace{\frac{\sum_{j\in\mathcal{J}_m} s_j e_j}{\sum_{j\in\mathcal{J}_m} s_j} - \bar{e}}_{\text{simple standard constraint}} \quad -a\left(\frac{\sum_{j\in\mathcal{J}_m} s_j w_j}{\sum_{j\in\mathcal{J}_m} s_j} - w_0\right) = 0$$

Therefore, a manufacturer's simple standard constraint is relaxed when its own footprint average is larger than that of the fleet, and vice versa.

Appendix B: Additional Tables

Table B.1: Manufacturers' initial characteristics in the U.S. market for 2007. Fuel economy expressed as harmonic mean.

Manufacturer	Sales (in 1,000)	Market share (in %)	Mean fuel economy (in mpg)	Std. dev. (in mpg)	# of car models
GM	1885.32	19.87	20.4	3.3	73
Toyota	1774.17	18.7	25.8	10.9	40
Ford	1179.71	12.43	19.7	4.2	75
Honda	1094.92	11.54	23	10.1	32
Chrysler	716.89	7.56	20.1	3.6	28
Nissan	701.89	7.4	21.9	5.8	22
Hyundai	426.5	4.49	22.1	4.8	21
Volkswagen	316.21	3.33	20.7	4.2	30
BMW	310.75	3.27	18.9	3.8	16
Mazda	264.79	2.79	21.9	3.0	17
Mercedes	227.13	2.39	16.7	2.1	22
Kia	213.09	2.25	23	4.9	14
Subaru	160.84	1.7	20.8	1.3	10
Mitsubishi	107.98	1.14	20.2	2.1	11
Suzuki	79.97	0.84	21.2	2.7	11
Porsche	28.55	0.3	17.7	2.4	8

Table B.2: Manufacturers' initial characteristics in the French market for 2007. Fuel economy expressed as harmonic mean.

Manufacturer	Sales (in 1,000)	Market share (in %)	Mean fuel economy (in mpg)	Std. dev. (in mpg)	# of car models
PSA	364.26	31.31	42.9	10.6	40
Renault	254.59	21.88	41.3	9.8	18
Volkswagen	131.6	11.31	39.0	9.2	62
Toyota	69.71	5.99	40.5	14.0	29
Ford	69.28	5.95	40.0	9.3	46
GM	57.56	4.95	39.4	9.2	34
Mercedes	39.7	3.41	35.0	12.3	30
BMW	39.05	3.36	35.89	9.0	17
Fiat	37.63	3.23	41.8	9.3	41
Suzuki	23.46	2.02	35.8	7.7	16
Hyundai	21.36	1.84	37.2	9.2	33
Nissan	20.85	1.79	35.9	10.4	25
Honda	10.59	0.91	39.2	16.5	11
Mazda	9.53	0.82	37.2	9.5	10
Chrysler	6.97	0.6	29.0	7.5	24
Mitsubishi	3.58	0.31	27.7	10.8	9
Porsche	1.96	0.17	19.6	3.4	4
Ssangyong	1.81	0.16	27.9	2.5	5

Table B.3: Distribution of compliers, payers, and non-constrained manufacturers for different levels of the standard and penalty in both countries

		U.S.			France		
Standard	Penalty ($/mpg)	# compliers	# payers	# non-constrained	# compliers	# payers	# non-constrained
+1%	300	0	10	6	3	12	3
+3%	300	2	11	3	3	12	3
+5%	300	0	13	3	3	14	1
+7%	300	2	13	1	4	14	0
+9%	300	1	14	1	1	17	0
+11%	300	0	15	1	1	17	0
+13%	300	0	15	1	0	18	0
+15%	300	0	15	1	0	18	0
+5%	75	0	13	3	0	17	1
+5%	200	0	13	3	3	14	1
+5%	400	1	12	3	4	13	1
+5%	600	2	11	3	5	12	1
+5%	800	2	11	3	7	10	1
+5%	1000	3	10	3	11	6	1
+5%	1200	3	10	3	13	4	1
+5%	1400	3	10	3	14	3	1
+5%	1600	3	10	3	14	3	1

Notes: The standard levels are percentages relative to the initial average fuel efficiency: 21.5 mpg in the U.S. and 40.2 mpg in France.

Table B.3 presents the distribution of manufacturers' reactions for both countries. As expected, the number of non-constrained manufacturers decreases in both countries as we increase the standard but is unchanged with an increase of the penalty. The number of compliers exhibits in general a bell-shaped curve in both countries when we increase the standard. Indeed, the status of manufacturers first switches from non-constrained to complier at low levels of the standard, and then switches from complier to payer for high levels of the standard. When the penalty is increased, we observe a marked movement from payers towards compliance in France. In contrast, in the U.S. this movement is not as pronounced yielding a final number of 3 compliers.

Table B.4: Equivalent feebate parameters for different levels of policy stringency in both countries

Standard	Penalty ($/mpg)	Feebate rate (τ)	Pivot point ($\tilde{e}$)	Feebate rate (τ)	Pivot point ($\tilde{e}$)
		U.S.		France	
+1%	300	98	24.1	102	42.3
+3%	300	118	24.3	119	42.8
+5%	300	133	24.6	158	43.2
+7%	300	139	25.1	200	43.6
+9%	300	168	25.2	253	44.1
+11%	300	180	25.5	285	44.7
+13%	300	182	26	300	45.4
+15%	300	184	26.5	300	46.2
+5%	75	34	24.7	54	43
+5%	200	90	24.7	122	43.1
+5%	400	173	24.6	185	43.2
+5%	600	243	24.6	235	42.9
+5%	800	304	24.6	269	42.6
+5%	1000	360	24.5	282	42.5
+5%	1200	413	24.4	286	42.4
+5%	1400	465	24.3	287	42.4
+5%	1600	515	24.2	288	42.4

Notes: The feebate rate τ represents the tax (subsidy) associated with a car which is 1 mpg above (below) the feebate pivot point $\tilde{e}$.

Table B.4 displays the parameters of the equivalent feebate schemes associated with each level of policy stringency. We find that increasing the level of the standard leads to increasing changes in the rate of the feebate up to the level of the penalty. The pivot point levels increase with the standard reflecting a larger tax base.

When the penalty increases, the rate of the feebate, τ, increases monotonically in both countries while the values of the feebate pivot points are most of the time decreasing. There is a trade-off between increasing the feebate rate and increasing the set of cars taxed when increasing the pivot point, therefore a decrease in the pivot point can be compensated by a greater feebate rate.

Table B.5: Imported models

Manufacturer	Brand	Models
BMW	BMW	Series 1
Ford	Ford	Galaxy, Mondeo, S-Max, Fiesta, Ka
	Volvo	C30
GM	Chevrolet	Matiz, Rezzo, Epica, Nubira, Kalos, Lacetti, Evanda
Hyundai	Hyundai	I30, Matrix, Getz, Atos, Tiburon
Mercedes	Mercedes	A Class, B Class
Mazda	Mazda	MX5, 2
Mitsubishi	Mitsubishi	Grandis, Colt
Nissan	Nissan	X-Trail, Primera, Micra, Note, Almera, Qashqai
Suzuki	Suzuki	Swift, Jimny, Wagon-R, Alto, Vitara, Gran Vitara, Ignis
Volkswagen	Audi	A5, S3
	Volkswagen	Caddy, Fox, Polo, Touran

Table B.6: New hybrid models and their brand

	U.S.		France	
Manufacturer	Brand	Model	Brand	Model
BMW	BMW	Series 3	Mini	Mini
Chrysler	Chrysler	300	Dodge	Caliber
Hyundai	Hyundai	Sonata	Hyundai	Tucson
Mazda	Mazda	3	Mazda	3
Mercedes	Mercedes	Class C	Mercedes	Class C
Mitsubishi	Mitsubishi	Eclipse	Mitsubishi	Pajero
Porsche	Porsche	911	Porsche	911
Suzuki	Suzuki	Forenza	Suzuki	Swift
Volkswagen	Volkswagen	Jetta	Volkswagen	Golf
GM	Chevrolet	Impala	Opel	Corsa
Kia	Kia	Spectra		
Subaru	Subaru	Legacy		
Fiat			Fiat	Punto
Ford			Ford	Fiesta
Nissan			Nissan	Qashqai
Renault			Renault	Clio

Appendix C: Online Appendix (not for publication)

Table C.1: Simulation results for the U.S. market, for different values of the standard

Policy type	Standard (%)	Sales (1,000s)	Profits + CS (bn \$)	Tax rev. (bn \$)	CO_2 (mill. tons)	W w/CO_2 (bn \$)	# prefer standard
Standard	+1	9,337	146.5	2.4	52.6	238.6	9
Feebate		9,345	146.7	2.4	52.6	238.9	
Standard	+3	9,295	145.5	3.1	52.2	238.1	9
Feebate		9,302	145.8	3.1	52.3	238.3	
Standard	+5	9,244	144.5	3.9	51.8	237.4	8
Feebate		9,253	144.7	3.9	51.9	237.7	
Standard	+7	9,191	143.3	4.8	51.5	236.8	7
Feebate		9,200	143.6	4.8	51.5	237.1	
Standard	+9	9,132	142.1	5.7	51	236	6
Feebate		9,140	142.3	5.7	51	236.3	
Standard	+11	9,066	140.7	6.7	50.5	235.1	6
Feebate		9,077	140.9	6.7	50.6	235.5	
Standard	+13	8,999	139.3	7.8	50.1	234.3	5
Feebate		9,011	139.5	7.8	50.1	234.7	
Standard	+15	8,930	137.8	8.8	49.6	233.4	6
Feebate		8,943	138.1	8.8	49.7	233.8	

Notes: Welfare includes the tax revenue and the CO_2 emissions using a value of 36\$/tCO_2. For the standard regulation, $\phi = 300$ \$/mpg.

Table C.2: Simulation results for the French market, for different values of the standard

Policy type	Standard (%)	Sales (1,000s)	Profits + CS (bn $)	Tax rev. (bn $)	CO_2 (mill. tons)	W w/CO_2 (bn $)	# prefer standard
Standard	+1	1,146	14.4	0.2	2.5	28.1	7
Feebate		1,150	14.5	0.2	2.5	28.2	
Standard	+3	1,139	14.3	0.2	2.5	28	5
Feebate		1,144	14.4	0.2	2.5	28.1	
Standard	+5	1,131	14.2	0.3	2.5	27.9	5
Feebate		1,135	14.3	0.3	2.5	28	
Standard	+7	1,120	14.1	0.4	2.5	27.7	5
Feebate		1,124	14.1	0.4	2.5	27.8	
Standard	+9	1,106	13.9	0.5	2.4	27.5	4
Feebate		1,108	13.9	0.5	2.4	27.5	
Standard	+11	1,090	13.6	0.7	2.4	27.2	4
Feebate		1,090	13.6	0.7	2.4	27.2	
Standard	+13	1,072	13.3	0.9	2.3	27	–
Feebate		1,072	13.3	0.9	2.3	27	
Standard	+15	1,054	13.1	1.2	2.3	26.7	–
Feebate		1,054	13.1	1.2	2.3	26.7	

Welfare includes the tax revenue and the CO_2 emissions using a value of 36\$/tCO_2. For the standard regulation, $\phi = 300$ \$/mpg. In the last two rows, since the feebate rate equals the value of the penalty, manufacturers are indifferent between the two policies.

Table C.3: Simulation results for the U.S. market, for different values of the penalty

Policy type	Penalty ($/mpg)	Sales (1,000s)	Profits + CS (bn $)	Tax rev. (bn $)	CO_2 (mill. tons)	W w/CO_2 (bn $)	# prefer standard
Standard	75	9,422	148.3	1.2	53.4	239.8	8
Feebate	75	9,423	148.3	1.2	53.4	239.8	
Standard	100	9,401	147.9	1.5	53.2	239.5	8
Feebate	100	9,402	147.9	1.5	53.2	239.6	
Standard	300	9,244	144.5	3.9	51.8	237.4	8
Feebate	300	9,253	144.7	3.9	51.9	237.7	
Standard	500	9,109	141.5	5.6	50.6	235.2	8
Feebate	500	9,135	142.2	5.6	50.8	236.1	
Standard	700	8,991	139.1	6.8	49.6	233	7
Feebate	700	9,041	140.2	6.8	49.9	234.6	
Standard	900	8,890	136.9	7.4	48.8	230.8	7
Feebate	900	8,970	138.8	7.4	49.2	233.3	
Standard	1100	8,802	135.1	7.7	48	228.7	7
Feebate	1100	8,921	137.8	7.7	48.6	232.2	
Standard	1300	8,728	133.6	7.6	47.3	226.5	6
Feebate	1300	8,891	137.2	7.6	48.2	231.4	
Standard	1500	8,667	132.3	7.2	46.7	224.4	6
Feebate	1500	8,880	137	7.2	47.9	230.7	
Standard	1750	8,606	131.1	6.2	46.1	221.7	6
Feebate	1750	8,891	137.3	6.2	47.6	230.1	

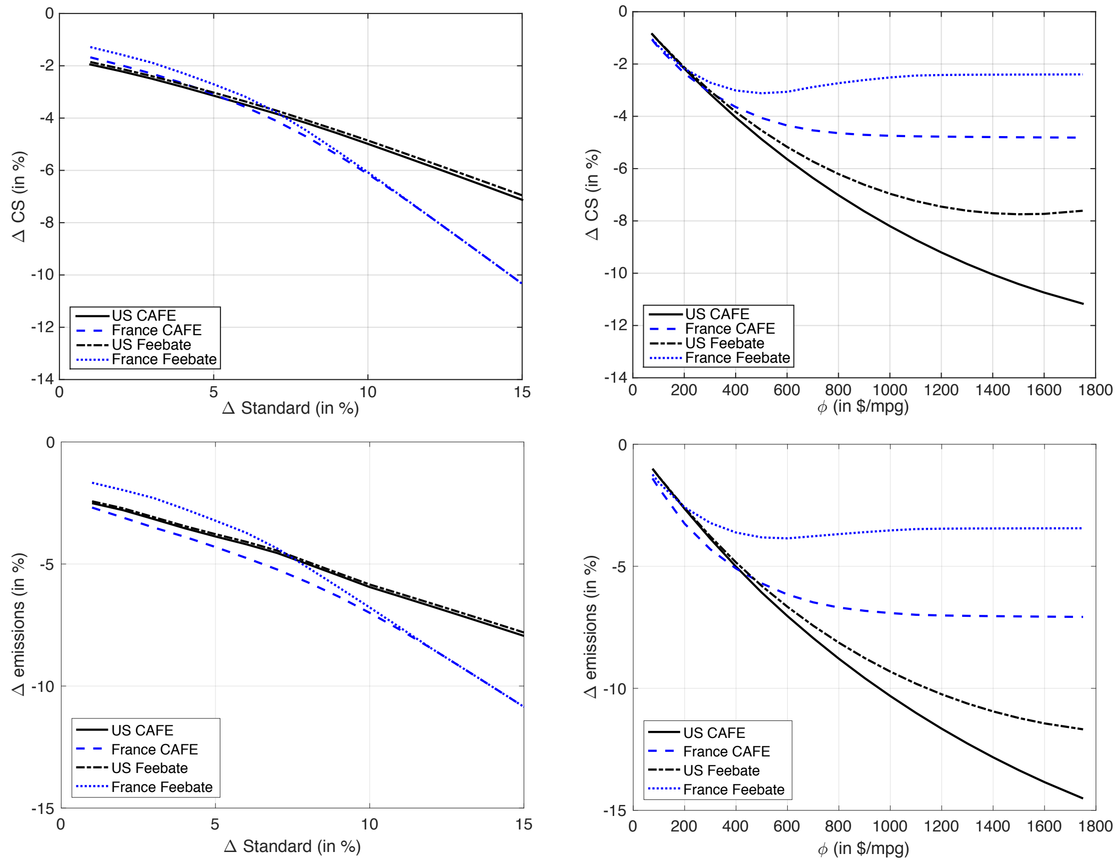
Notes: Notes: Welfare includes the tax revenue and the CO_2 emissions using a value of 36$/t$CO_2$. The level of the standard is fixed at 5% over the initial mpg.

Table C.4: Simulation results for the French market, for different values of the penalty

Policy type	Penalty ($/mpg)	Sales (1,000s)	Profits + CS (bn $)	Tax rev. (bn $)	CO_2 (mill. tons)	W w/CO_2 (bn $)	# prefer standard
Standard	75	1,152	14.5	0.2	2.6	28.2	5
Feebate	75	1,152	14.5	0.2	2.6	28.2	
Standard	100	1,149	14.5	0.2	2.5	28.2	5
Feebate	100	1,150	14.5	0.2	2.5	28.2	
Standard	300	1,131	14.2	0.3	2.5	27.9	5
Feebate	300	1,135	14.3	0.3	2.5	28	
Standard	500	1,121	14.1	0.3	2.4	27.6	5
Feebate	500	1,131	14.2	0.3	2.5	27.8	
Standard	700	1,116	14	0.2	2.4	27.3	5
Feebate	700	1,133	14.3	0.2	2.5	27.8	
Standard	900	1,114	14	0.1	2.4	27.2	5
Feebate	900	1,136	14.3	0.1	2.5	27.8	
Standard	1100	1,113	14	0	2.4	27.1	5
Feebate	1100	1,138	14.3	0	2.5	27.8	
Standard	1300	1,113	14	0	2.4	27.1	5
Feebate	1300	1,138	14.4	0	2.5	27.8	
Standard	1500	1,113	14	0	2.4	27.1	5
Feebate	1500	1,138	14.4	0	2.5	27.8	
Standard	1750	1,113	13.9	0	2.4	27.1	5
Feebate	1750	1,138	14.4	0	2.5	27.8	

Notes: Notes: Welfare includes the tax revenue and the CO_2 emissions using a value of 36\$/tCO_2. The level of the standard is fixed at 5% over the initial mpg.

Figure C.1: Consumer surplus and emissions changes by policy instrument and country



Notes: For the first column, $\phi = 300\$/\text{mpg}$. In the second column, the standard is set to 5% above initial mpg.